

Research Problem Review 76-13

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STUDY OF PSYCHOLOGICAL (AND ASSOCIATED  
PHYSIOLOGICAL) EFFECTS ON A TANK CREW  
RESULTING FROM BEING BUTTONED UP

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PHYSIOLOGICAL) EFFECTS ON A TANK CREW  
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## FOREWORD

The Fort Hood Field Unit of the Army Research Institute for the Behavioral and Social Sciences (ARI), by assessing the human performance aspects of man/weapons systems evaluations in field situations, provides support to Headquarters, TCATA (TRADOC Combined Army Test Activity, formerly called MASSTER--Modern Army Selected Systems Test Evaluation & Review). A war using modern weapons systems is likely to be both intense and short; U.S. man/weapons systems must be effective enough, immediately, to offset greater numbers of an enemy. Cost-effective procurement of improved and/or new combat systems requires testing that includes evaluation in operational settings similar to those in which the systems would be used, with troops representative of those who would be using the systems in combat. The doctrine, tactics, and training packages associated with the systems being evaluated must themselves also be tested and refined as necessary.

The present report presents the results of a literature survey designed to provide information on the psychological and associated physiological factors that might be expected to affect tank crew performance while operating buttoned up. The report also lists recommended design changes to be considered or incorporated into our present tanks so that buttoned-up or continuous operations can be sustained. The findings provide a background against which armor doctrine and training concerning buttoned-up operations can be formulated.

ARI research in this area is conducted as an in-house effort augmented by contracts with organizations with unique capabilities for human factors research. The present research was done jointly by personnel from the ARI Fort Hood Field Office and the Human Resources Research Organization (HumRRO), under contract DAHC 19-75-C-0025, and is responsive to the special requirements of TCATA and the objectives of RDTE Project 2Q763731A755, "Human Performance in Field Assessment," FY 1976 and 1977 Work Programs.

  
J. E. UHLANER,  
Technical Director

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# STUDY OF PSYCHOLOGICAL (AND ASSOCIATED PHYSIOLOGICAL) EFFECTS ON A TANK CREW RESULTING FROM BEING BUTTONED UP

## BRIEF

### Requirement:

Tanks in any future mid-intensity or high-intensity conflict will be required to operate in the buttoned up mode much more than in the past. Crews will button up for short periods when faced with overhead artillery, small arms fire, or aircraft attack. In an environment contaminated by nuclear, chemical, or biological agents, they may be forced to button up for much longer periods. It has been hypothesized that performance in some critical areas would be degraded during buttoned up operations. It was further hypothesized that much of the degradation would be attributable to psychological (and associated physiological) factors associated with being buttoned up. The research was implemented to determine what psychological and associated physiological factors affect tank crew performance during both short-term and long-term buttoned up operations.

### The objectives of the research were to:

- Determine from available documentation what psychological (and associated physiological) factors might be expected to affect crew performance while buttoned up.
- Determine from available documentation what amount of degradation (if any) has been observed on task performance while buttoned up.
- Determine from available documentation what design changes need to be considered or incorporated into our present tanks, and to provide data on design requirements for future tanks.
- Provide information on whether continuous operations in the buttoned-up mode is militarily feasible with our present tanks.
- Conduct experimental studies and/or field research designed to determine the extent of performance degradation on critical tasks, and/or to determine means of minimizing performance degradation where previously observed through improved operating procedures or through equipment modifications.

### Procedure:

The work was planned to be conducted in two phases. In Phase I, literature and other information relevant to the objectives would be accumulated and reviewed, and research needs would be determined. In Phase II, experimental studies based on the determined need would be planned and executed. It was presumed that these studies would be oriented toward

determining the extent of degradation in the performance of critical tasks, or toward minimizing performance degradation where previously observed.

The review of available information was accomplished and three field studies were proposed for investigation during the first year. However, due to the limited support which could be provided by the units tasked with the support mission, work was actually initiated on only one of the efforts.

#### Principal Findings:

- Tank crews can function continuously in the open hatch mode with little or no degradation in performance for periods up to 48 hours in duration.
- Simply buttoning up for periods of up to 48 hours has little effect on performance.
- In general, wearing Chemical, Biological, and Radiological (CBR) protective equipment does not appear to degrade performance until the cumulative effects of various physiological factors begin to affect performance.
- Our present tanks are not designed to sustain buttoned-up operations for extended periods.
- The tank heating and ventilation systems may not be adequate to sustain buttoned-up conditions.
- Personnel wearing CBR protective clothing in buttoned up tanks during high ambient temperature conditions may become heat prostration casualties in less than an hour.

#### Utilization of Findings:

The information provided indicates that tank crews can operate buttoned up for periods up to 48 hours or even longer if the tank is designed properly to support such operations. The incorporation of recommended specific modifications in both current and future armored vehicles will greatly improve US capability to operate in the buttoned-up mode. These findings should also provide a background against which armor doctrine and training concerning buttoned-up operations can be formulated.

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## CHAPTER 1

### INTRODUCTION

The stated doctrine of potential enemies dictates the employment of chemical weapons in tactical operations, biological weapons in strategic operations, and nuclear weapons as required. Nuclear weapons have not been used since 1945 and chemical weapons not since World War I. Biological weapons have never been used. Nevertheless, the armies of the major powers have Nuclear, Biological, and Chemical (NBC) weapons in their inventories.

It is the policy of the US to employ nuclear weapons only if the enemy uses them first, or when conventional weapons have been found inadequate to ensure our survival. The US has also renounced the use of biological agents, and will use chemical weapons only if the enemy uses them. The armies of potential enemies have these types of weapons and are prepared to use them. Unless our forces know how to fight in an unconventional environment, it could drastically reduce our capability to wage war.

Threat forces are also expected to employ massive amounts of artillery prior to attacking. Our armored forces will be required to move out from under these artillery fires and be able to shoot and move.

It is clear, that in any future conflict against a sophisticated enemy, our armored forces will probably have to operate in an environment never before encountered. They will undoubtedly be forced to operate with hatches closed much of the time, even if only for protection from conventional artillery. If NBC weapons are employed, closed-hatch operations will become the standard. This mode of operations has

been referred to as *buttoned-up* operations, and is the subject of this report.

Threat forces are well equipped with a complete array of individual and vehicular protective gear for operations in an NBC environment. For example, most threat armored vehicles feature positive-pressure protection with filtered air for vehicle crews when buttoned up. Threat forces also train extensively for operations on an NBC battlefield. US armored vehicles lack many of these design features, and US forces receive only minimal training in buttoned-up operations.

As our tank designs have changed, the amount of work and movement space within the tank has decreased. The addition of more sophisticated equipment and the desire for heavier armor protection, along with increased weapon sizes, may decrease the liveable space even more in future tanks. Nevertheless, in anticipation of the use of NBC weapons, and the lingering hazards which may last for days and cover many square miles, our tank crews may have to operate on the NBC battlefield and remain in contaminated areas for long periods of time while buttoned up. The periods of time will vary, depending on the degree of contamination, the protection available, and the military situation at the time. Therefore, it is imperative that the problems associated with buttoned-up operations be determined, and that these problems be solved.

It has been hypothesized that closed-hatch operations would tend to affect performance adversely. It has also been hypothesized that performance would degrade more rapidly during buttoned-up operations than during open-hatch operations. Finally, it was hypothesized that much of the presumed degradation would be a product of psychological (and associated

physiological) factors resulting from being buttoned up. The current research effort was originally proposed to address the validity of these hypotheses.

More recently, the major objective of this research has been to *examine both the short-term and long-term effects of operating in a buttoned-up mode.* In particular, this research has attempted to:

1. Determine from available documentation what psychological (and associated physiological) factors might be expected to affect crew performance while buttoned up.
2. Determine from available documentation what amount of degradation (if any) has been observed on task performance while buttoned up.
3. Determine from available documentation what design changes need to be considered or incorporated into our present tanks, and to provide data on design requirements for future tanks.
4. Provide information on whether continuous operations in the buttoned-up mode is militarily feasible with our present tanks.
5. Conduct experimental studies and/or field research designed to determine the extent of performance degradation on critical tasks, and/or to determine means of minimizing performance degradation where previously observed through improved operating procedures or through equipment modifications.

This research is seen as a continuing effort. This report describes only the work completed during the first year. Unfortunately, the initiation of the field work planned for this first year was considerably delayed. The austere budgets of the units that support research performed at HQ, MASSTER, Fort Hood, Texas, severely limited the availability of equipment. Therefore, final results are not available on any of the efforts in time to be included in this report. Some preliminary findings concerning determination of optimum turret traversing rates are available. Final results will be reported in the early part of the second year effort.

The remainder of this report is organized into four chapters. Chapter 2 contains the information on psychological and physiological factors presumed to affect tank crew performance while buttoned up. The major findings of the literature review concerning these factors are summarized in Chapter 3. Chapter 4 contains a list of design recommendations to be considered in tank design as well as recommended areas for future research. Chapter 5 describes, in brief, three research areas which are either underway or are being considered for further study, and describes some preliminary findings concerning target acquisition by the tank commander from a buttoned-up tank.

## CHAPTER 2

### LITERATURE REVIEW

#### Factors Affecting Crew Performance During Buttoned-up Operations

In order to ascertain what related research had been previously accomplished, and to provide a basis for determining future research needs, a literature search was initiated. Over 300 documents were obtained and examined during the course of the literature search. While the literature was extensive and diverse in content, the bulk of the information was only indirectly relevant to armor crew buttoned-up operations. It was found that the majority of such research has been directed toward confinement and personnel functions in space capsules or underwater habitats. Many of the most relevant studies, i.e., those actually dealing with occupancy of armored vehicles, were accomplished by British researchers working with the British armor forces. Most of these latter reports are classified and cannot be cited here. They are, however, reviewed in the classified Appendix and must be obtained separately.

After extensive review of the available literature, it was decided to discuss the various factors which are presumed to affect performance under the following broad categories:

- . Environmental Conditions
- . Confinement
- . Combat Stress
- . Noise
- . Vibration
- . Radiation
- . Habitability (Personal Factors)
- . Human Engineering
- . Work/Rest Cycles
- . Enhancement of Performance by Drugs
- . Toxic Environment
- . Sustained/Continuous Operations

The arbitrary nature of this classification scheme is recognized. It is also realized that the titles presented are open to varying interpretation, and must be further defined in the discussion. The schema chosen, however, is suitable for discussing those factors believed to be of critical importance in buttoned-up operations.

### Environmental Conditions

For purposes of this report, the meaning of the term *environmental conditions* will be largely constricted to conditions associated with the internal atmosphere of the vehicle. Therefore, in this review, this term refers to conditions of temperature, humidity, and air flow, and their interrelationships with the physical environment as well as the factors which change or influence these conditions.

In a tactical military situation, there is naturally less concern with how these conditions affect the physical comfort of soldiers than with how they affect performance of essential tasks. Therefore, the ensuing discussions are oriented toward determining the acceptable limits of environmental conditions in terms of their effects on the various aspects of human performance.

### Temperature Effects-Cold

The extremities of the body are most susceptible to cold injury because they present the largest exposed surface for heat loss. For example, poor circulation in the extremities increases the danger of cold injury. Findikyan, Duke, and Sells,<sup>1</sup> in their review of cold stress,

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<sup>1</sup>N. Findikyan, M. Duke, and S. Sells. *Stress Reviews: I. Thermal Stress-Cold*, Technical Report No. 8, Institute of Behavioral Research, Texas Christian University, Fort Worth, July 1966.

stated that exposure to cold produces numbness of the fingers, which leads to deterioration of performance, particularly on tasks requiring fine manual dexterity. As a consequence, duties requiring manipulation of knobs, switches, pushbuttons, keys, screws, and nuts and bolts become almost impossible to perform. This typically occurs when the skin temperature of the fingers drops below about 60°F. Hands and fingers can be kept warm by reducing their exposure to cold in a number of ways. Typically, gloves or mittens are worn. However, gloves are not adequate to maintain hand skin temperature above 60°F after long exposure to ambient temperatures below 30°F. Mittens of fur and leather materials can be used down to about 20°F to maintain the finger skin temperature at 60°F.<sup>2</sup> In either case, of course, much of the use of the hands is lost. Standard Army issue arctic wear is quite adequate for protecting the trunk, limbs, and head, but the maintenance of satisfactory temperatures in the extremities, especially the hands, remains a problem for which no satisfactory solution has been found.

So long as individuals are properly clothed, there are few indications that cold affects performances not requiring fine manual dexterity. There is some evidence that vision is affected in studies reviewed by Reevesman, Hollis, and Mattson.<sup>3</sup> They concluded that there is apparently some change in vision in the arctic. The studies reviewed indicated that there is greater eyestrain and a greater tendency to errors in distance

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<sup>2</sup>W. Fenning, P. Jackson, and R. Kelley. *Reference Sources in the Physiology of Extreme Environmental Temperatures*, Engineering Research Institute, University of Michigan, Ann Arbor, May 1954.

<sup>3</sup>S. Reevesman, J. Hollis, and J. Mattson. *A Literature Survey of Human Performance Under Arctic Environment*, RDD Technical Memo 6, Department of the Army, Washington, D.C., December 1953.

judgment under arctic conditions. However, according to Williams and Kitching,<sup>4</sup> the size of the visual field is not affected. They report no changes in the area of visual field in two subjects who were exposed to a temperature of -50°F for one hour and to lower temperatures for greater durations.

Several means of minimizing the effects of cold in armored vehicles have been considered. The British have used warm air directed over the tank gunners' hands to maintain their tactual sensitivity on the traversing and elevating controls.<sup>5</sup>

Fenning, et al,<sup>6</sup> conducted a literature search on a project dealing with the evaluation of possible methods of heating, cooling, and ventilating combat tanks under extreme environmental conditions. They recommended that the compartment be heated to between 20°F (minimum temperature) and 25°F (maximum temperature). The minimum figure results from the desirability of maintaining warmth with as little bulkiness of clothing as possible. Also, at temperatures below this figure, it is almost impossible to maintain the fingers at a temperature conducive to manual dexterity. At 20°F, mittens can be used to maintain finger warmth, and air flows from the heating system can be directed over controls to provide warmth when mittens are removed to operate them. The maximum temperature of 25°F is specified, in this instance, not only from an economy standpoint, but also in view of the fact that higher temperatures might result in overheating

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<sup>4</sup>C. Williams and J. Kitching. *The Effects of Cold on Human Performance*, NRCC, Ottawa, Canada, March 1942.

<sup>5</sup>N. Findikyan, M. Duke, and S. Sells, *op. cit.*, 1966.

<sup>6</sup>W. Fenning, P. Jackson, and R. Kelley, *op. cit.*, 1954.

of the body in its heavy clothing. Lighter clothes for the crewmen might not be possible, since in many situations they may have to dismount frequently from the vehicle.

Subjective feelings of coldness can be noticeably altered without changes in temperature by manipulating the environment. For example, it is common knowledge that colors such as blue and green are called "cool" colors, while orange, red, and brown are called "hot" colors. People feel warmer in rooms where the walls and decor are in hot colors. It is also known that bright sunny days are psychologically warmer than dark cloudy days. Finally, even though there is no substantial differences in the non-evaporative heat loss of the skin, whether the humidity is high or low, an increase in humidity almost invariably is accompanied by feelings of discomfort during either warm or cold weather. The incidence and intensity of shivering and the sensation of cold are greater when humidity is high, even when skin temperatures are the same.

<sup>7</sup>Tromp has suggested that there is a psychological quality to the rate of air movement. An optimum rate creates an invigorating environment, while variable (rather than constant) rates of air movement are perceived as more bracing. Although his observations apply primarily to air movements in a room or building, where total movement is typically small, they should apply equally well to the inner compartments of tanks.

The human body itself is capable of some accommodation to cold. Biological changes (e.g., vasoconstriction) begin immediately any time the ambient temperature falls below 68°F in the body's effort to maintain a constant temperature. Long-range adaptation, called *acclimatization*, is

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<sup>7</sup>S. Tromp (ed.). *Medical Biometeorology*, New York: Elsevier Publishing Company, 1963.

largely achieved in about one week, but may not be complete for as much as two or three weeks.<sup>8</sup>

Data on the ability of the "physically fit" man to withstand cold better than the unfit individual is meager,<sup>9</sup> despite the general acceptance of the concept. One of the apparent problems in this area is the definition and quantification of measures of physical fitness. The available literature indicates that a physically fit person performing well in temperate weather will not necessarily perform as well in arctic and sub-arctic weather. Apparently, the particular kind of physical fitness required to combat cold stress is that which is acquired through acclimatization, conditioning and training.

#### Temperature Effects-Heat

A number of investigators have examined the effects of high ambient temperatures on human performance. In general, the results have been consistent, at least with respect to physical tasks. For example, Welsh<sup>10</sup> suggested that until Effective Temperatures (ETs) exceed about 90°F, performance on tasks not requiring great physical effort is little affected. Bond and Sleight<sup>11</sup> expressed agreement with this position.

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<sup>8</sup>W. Macfarlane. "General Physiological Mechanisms of Acclimatization," in S. Tromp (ed.), *Medical Biometeorology*, New York: Elsevier Publishing Company, 1963, pp 372-417.

<sup>9</sup>N. Findikyan, M. Duke, and S. Sells, *op. cit.*, 1966.

<sup>10</sup>B. Welsh. "Ecological Systems," in J. Brown (ed.), *Physiology of Man in Space*, New York: Academic Press, 1963, pp 309-334.

<sup>11</sup>H. Bond and R. Sleight. *Human Factors in the Design of Desert Equipment*, HEL Contract DA-36-034-0-ORD-1642, US Army Human Engineering Laboratory, Aberdeen Proving Ground, Maryland, December 1954.

stating that the heat generally experienced under desert conditions, because of low humidity and tolerable ETs, had little if any effect on the performance of mental or psychomotor tasks. In cases where impairment in performance sometimes occurred, this was ascribed to physiological distress that took place as the body attempted to maintain thermal equilibrium.

Eichna, et al.,<sup>12</sup> have found that the Wet Bulb Temperature (WBT) is the limiting factor with respect to the effects of heat on human performance, with Dry Bulb Temperature (DBT) being of only minor importance. Below a WBT of 91°F, men work easily and efficiently. The range in which men are capable of moderately hard work is 91-94°F WBT, but decreased efficiency and alertness are evident. Above 94°F WBT, major disability soon occurs, the average limit being about one hour of work. Lee<sup>13</sup> (in a study dealing with tank air-conditioning) found that the *critical level of ET for tolerance to heat lies between 88°F and 92.5°F*, as reported by Fenning, et al. Connell,<sup>14</sup> after reviewing the effects of high ambient temperature on performance, suggested an upper limit of 85°F for performance of sedentary tasks without impairment, as reported by Duke, et al.,<sup>15</sup>. McBlair, Rambaugh, and Fozard<sup>16</sup> recommended maintaining temp-

<sup>12</sup>L. Eichna, et al. "Upper Limits of Environmental Heat and Humidity Tolerated by Acclimatized Men Working in Hot Environments," *Journal of Industrial Hygiene*, March 1945, 27, 59-84.

<sup>13</sup>D. Lee. *Trial Tank Air Conditioning Equipment-Hot Room Tests*, AFV 39, October 1943.

<sup>14</sup>L. Connell. *The Effects of Heat Upon the Performance of Men in High Speed Aircraft. A Critical Review*, ADC Report 151-1-17, Office of Naval Research, Washington, D.C., June 1948.

<sup>15</sup>M. Duke, N. Findikyan, J. Anderson, and S. Sells. *Stress Reviews: II. Thermal Stress-Heat*, Technical Report No. 11, Institute of Behavioral Research, Texas Christian University, Fort Worth, May 1967.

<sup>16</sup>W. McBlair, D. Rambaugh, and J. Fozard. *Environmental Effects on Human Performance, Including Fatigue. Part 4. Ventilation, Temperature, Humidity*, SDSCF, 1955.

eratures at 85°F DBT, 75°F WBT, for maximum efficiency, as reported by Duke, et al.

Field studies (e.g., Minard, et al.,<sup>17</sup>) involving continuous exposure for periods of at least several days report significant physiological changes as well as performance impairment of combat efficiency under high thermal stress. Minard's subjects were unacclimatized paratroopers participating in combat exercises in Panama.

As can be seen from the research described in the preceding paragraphs, performance deterioration can be expected when ET reaches the vicinity of 90°F. However, under proper conditions man can survive in much higher ambient temperatures. For example, Brouha<sup>18</sup> states that the upper limit of DBT which man can tolerate is relatively high: resting men have withstood 15-minute exposures to temperatures up to 250°F without ill-effects. At higher temperatures, humidity assumes greater importance, since the cooling in these circumstances is not limited by man's ability to perspire, but by the capacity of the atmosphere to absorb additional moisture. The limiting factor to evaporative heat regulation in hot, humid environments is the capacity of the air for absorbing water. In hot, dry environments, the limiting factor is man's ability to produce enough perspiration to maintain the evaporative requirement for regulating body temperature.

High ambient temperatures do not affect performance on all types of tasks equally, as shown by studies of the effects of temperature on

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<sup>17</sup>D. Minard, G. Grayeb, R. Singer, and J. Kingston. *Heat Stress During Operation, Banyan Tree I*, Report No. 5, Naval Medical Research Institute, Bethesda, Maryland, July 1961.

<sup>18</sup>L. Brouha. *Physiology in Industry*, New York: Pergamon Press, 1960.

specific kinds of tasks. Carpenter<sup>19</sup> found that as ambient temperature increased, intelligence (as measured by performance on the Resistance Box test) showed a decrement, with the deterioration becoming statistically significant at about 90°F ET. When body temperature was elevated to 101°F, Bean and Eichna<sup>20</sup> found that accuracy in mathematical calculations decreased. These findings were consistent with those of Wilkinson, et al.,<sup>21</sup> and Fox, et al.,<sup>22</sup> as they found an impairment in the ability to add at 101°F, when compared with performance at normal body temperatures. However, raising body temperature to only 99°F produced a slight improvement.

Mackworth,<sup>23</sup> in his study of heat and humidity, found evidence for impairment of perceptual functioning, as reported by Fenning, et al. His primary findings were: (1) hot, moist atmospheres impair the accuracy with which faint visual signals are detected in a relatively monotonous situation; (2) responses tend to become sluggish, but do not decline as markedly as accuracy of work; (3) optimum DBTs and WBTs for visual search

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<sup>19</sup>A. Carpenter. *The Effect of Room Temperature on the Performance of Resistance Box Test: A Performance Test of Intelligence*, Report No. APO 50, Medical Research Council, Applied Psychology Unit, 1946.

<sup>20</sup>W. Bean and L. Eichna. "Performance in Relation to Environmental Temperatures," *Federal Proceedings*, 1943, 2, 144-158.

<sup>21</sup>R. Wilkinson, R. Fox, R. Goldsmith, I. Hampton, and H. Lewis. "Psychological and Physiological Responses to Raised Body Temperature," *Journal of Applied Psychology*, 1964, 19, 287-291.

<sup>22</sup>R. Fox, R. Goldsmith, I. Hampton, and R. Wilkinson. "The Effects of a Raised Body Temperature on the Performance of Mental Tasks," *Journal of Physiology*, June 1963, 167(1), 22<sup>p</sup>-23 (abstract).

<sup>23</sup>N. Mackworth. *Effects of Heat and High Humidity on Prolonged Visual Search as Measured by the Clock Test*, report prepared for the Habitability Sub-Committee of the RNPRC, February 1946.

are 85°F and 75°F, respectively; and (4) performance deterioration becomes statistically significant at 95°F WBT and 83°F DRT. However, not all perceptual tasks appear to be affected. For example, Loeb and Jeantheau,<sup>24</sup> as reported by Duke, *et al.*, found no detrimental effects of high temperature on a monitoring task carried out in a troop carrier. The temperature ranges studied were 65°/75°F to 110°/125°F.

Reaction time does not appear to be affected by heat. Duke, Findikyan, Anderson, and Sells<sup>25</sup> reached this conclusion on the basis of consistent findings in their review of the literature on thermal stress. Other work reviewed by these authors indicates less consistency in findings concerned with mental and perceptual tasks. This fact was also observed by McBlair, *et al.*,<sup>26</sup> who reported that physical tasks were more consistently impaired by heat than mental tasks. They also observed that simple tasks were less affected by heat than complex tasks.

Given time and opportunity to become acclimated, man's performance while enduring high ambient temperatures improves and becomes more consistent. Acclimatization enables him to work in hot climates with lower body temperatures, lower heart rate, and more stable blood pressure. Morgan, *et al.*,<sup>27</sup> reported that: *Acclimatization takes from three to 12 days approximately, and is more effective if men work in the hot climate*

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<sup>24</sup>M. Loeb and E. Jeantheau. "The Influence of Noxious Environmental Stimuli on Vigilance," *Journal of Applied Psychology*, 1958, 42, 47-49.

<sup>25</sup>M. Duke, N. Findikyan, J. Anderson, and S. Sells, *op. cit.*, 1967.

<sup>26</sup>W. McBlair, R. Rambaugh, and J. Fozard, *op. cit.*, 1955.

<sup>27</sup>C. Morgan, J. Cook, A. Chapanis, and M. Lund. *Human Engineering Guide to Equipment Design*. New York: McGraw-Hill, 1963.

them if they simply rest during the acclimatization period. Acclimatization lasts approximately two weeks after the individual leaves the hot climate, and then declines slowly, so that after two months it is lost. Bean and Eichna,<sup>28</sup> and Eichna, Bean, and Ashe<sup>29</sup> report very similar findings. They found that the acclimatization process begins upon the first day of exposure, progresses rapidly, and then becomes fairly well established after a period of three to ten days.

Torrance,<sup>30</sup> in discussing acclimatization in his survival research summary, as reported by Duke, *et al.*, mentioned the opinion of the physiologist, Adolph, who stated that there is no evidence for adaptation to dehydration, although the evidence for heat adaptation is satisfactory. The importance of compensating for water loss in extreme heat by adequate water intake is an important factor in heat tolerance, regardless of adaptation. Rohles, *et al.*,<sup>31</sup> point out that water consumption of even sedentary personnel at an ET of approximately 92°F can exceed two gallons per day. These facts are certainly of interest in any research on buttoned-up operations, as no provision for carrying water internally in the amounts apparently necessary has been made for US Army armored vehicles.

Means of combating heat in armored vehicles have received little thought. Ventilated garments have been employed in space capsules and

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<sup>28</sup>W. Bean and L. Eichna, *op. cit.*, 1943.

<sup>29</sup>L. Eichna, W. Bean, and W. Ashe. *Operations at High Temperatures. Studies of Men in Simulated Jungle (Humid) Heat*, Project No. 2, 2-7, 2-11, 2-13, 2-15, 2-17, 2-19, US Army Medical Research and Division Command, Fort Knox, Kentucky, October 1943.

<sup>30</sup>P. Torrance. *Surviving Emergencies and Extreme Conditions. A Summary of Six Years of Research*, unpublished report.

<sup>31</sup>F. Rohles, R. Nevins, and P. McNall. *Human Physiological Responses to Shelter Environment*, Report No. 2, Institute for Environmental Research, Kansas State University, Manhattan, February 1967.

aircraft cockpits which provide a power source. The Germans experimented with cooling devices for their tank crews during World War II (WWII), but never actually employed them in combat. It may soon be possible for environmental engineering to extend the technology employed by the National Aeronautics and Space Administration (NASA) and the United States Air Force (USAF) to the individual soldier in an armored vehicle.

### Effects of Humidity and Ventilation

Fenning, Jackson, and Kelley<sup>32</sup> concluded from their literature survey that: In environments where humidity is extremely low, the lack of moisture may result in drying of the mucous membranes and reduction of the fluid on the surface of the eyes. No permanent damage to the tissue results, but irritation and temporary discomfort may be experienced, such as increased sensitivity of the eyes, sore throat, etc. *The comfortable range for humidity seems to be between 40 and 60 percent; change in either direction may bring about performance impairment dependent upon the magnitude of the change and other environmental conditions.*

Duke, et al.,<sup>33</sup> reported that Pepler<sup>34,35,36,37,38,39</sup> adequately demonstrated that performance on tasks involving vigilance, or tasks involving

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<sup>32</sup>W. Fenning, P. Jackson, and R. Kelley, *op. cit.*, 1954.

<sup>33</sup>M. Duke, N. Findikyan, J. Anderson, and S. Sells, *op. cit.*, 1967.

<sup>34</sup>R. Pepler. *The Effect of Climatic Factors on the Performance of Skilled Tasks by Young European Men Living in the Tropics: IV. A Task of Prolonged Visual Vigilance*, Report 53/766, Royal Naval Personnel, January 1953a.

<sup>35</sup>R. Pepler. *The Effect of Climatic Factors on the Performance of Skilled Tasks by Young European Men Living in the Tropics: A Task Continuous Pointer Alignment -- Experiment One*, Report 53/766, Royal Naval Personnel, January 1953b.

<sup>36</sup>R. Pepler. The Effect of Climatic Factors on the Performance of Skilled Tasks by Young European Men Living in the Tropics: A Task of Continuous Pointer Alignment -- Experiment Two, Report 53/768, Royal Naval Personnel, February 1953c.

<sup>37</sup>R. Pepler. The Effect of Climatic Factors on the Performance of Skilled Tasks by Young European Men Living in the Tropics: A Task of Morse Code Reception, Report 53/769, Royal Naval Personnel, February 1953d.

<sup>38</sup>R. Pepler. The Effect of High Air Temperature and Humidity on Performance, PPRC Report 961.s., Royal AF IAM, Engineering, January 1956.

<sup>39</sup>R. Pepler. "Warmth and Performance: An Investigation in the Tropics," *Ergonomics*, 1958, 2, 63-88.

psychomotor skills such as tracking or telegraphy, was poorer in moist than in dry climates. Pepler<sup>40</sup> reported that the optimum ET for tracking performance was 72.5°F, which is some 6-8°F cooler than the average tropical temperature. However, this decrement in performance in hot, humid climates as compared to dry climates may be the greater subjective stress associated with the moist atmosphere.<sup>41</sup>

In relatively closed and occupied spaces, humidity is closely related to ventilation. With minimal ventilation, humidity is increased by the vaporization of water from breath and perspiration. Hicks,<sup>42</sup> in a series of studies on closed-hatch operations, found that condensation on the interior surfaces of test vehicles was a major problem. The

<sup>40</sup>R. Pepler. The Effect of Climatic Factors on the Performance of Skilled Tasks by Young European Men Living in the Tropics: A Task of Continuous Pointer Alignment at Two Levels of Incentive, Report 54/795, Royal Naval Personnel, November 1953a.

<sup>41</sup>H. Bond and R. Sleight, *op. cit.*, 1954.

<sup>42</sup>S. Hicks. The Effects of Confinement on the Performance of Combat Relevant Skills: Summary Report, Technical Memorandum 16-64, US Army Human Engineering Laboratory, Aberdeen Proving Ground, Maryland, 1964.

condensation tended to occur in the early morning hours at temperatures around 40°F. Crewmen found it difficult to rest against the walls of the vehicle as their clothing became wet. Water condensing on the ceiling also dropped on clothing and other gear stowed in the compartment. Some gear began to rust. Also, the vision blocks became fogged which would have made combat operations extremely hazardous. This research study is the only one located in the literature which described this particular problem. However, it certainly indicates the kind of problems that must be faced during buttoned-up operations in very moist climates with wide temperature variation without adequate ventilation. In well-ventilated spaces, internal humidity approximates external humidity. However, ventilation has an additional effect on body temperature. Moving air absorbs moisture more rapidly and, therefore, has a cooling effect on exposed body surfaces. In general, the greater the rate at which fresh air passes the body, the greater the cooling effect.

Ellis, et al.,<sup>43</sup> has pointed out the importance of the rate of air movement is the tolerance of temperature conditions. Some conditions that were tolerable with an air rate of 150 feet per minute became intolerable at 20 feet per minute. Lee,<sup>44</sup> as reported by Fenning, et al., conducted a study in New Guinea with tank crews. The crews were subjected to seven-hour test periods during which humid and dehumidified air was passed over their body surfaces by means of air jets or air distribution harnesses.

<sup>43</sup>F. Ellis, H. Ferris, A. Lind, and P. Newling. *The Upper Tolerable Limits of Warmth for Acclimatized European Men Working in the Tropics*, RNP 53-759, HM Stationery Office, Medical Research Council, Royal Naval Personnel Research Committee, London, 1953.

<sup>44</sup>D. Lee. *Field Trials of Methods of Tank Personnel Cooling Carried Out in New Guinea*, AFV 48, December 1943.

Air was delivered in quantities of eight Cubic Feet per Minute (CFM) and 16 CFM per man. The following conclusions were reached: (1) some form of personal cooling is essential for efficient operation of tank crews in the tropics; (2) of the cooling methods tested, the best was to supply each man with eight CFM of air, dehumidified to a dew point of 50°F; (3) the next best method was to supply 16 CFM per man of untreated air directly from the atmosphere; and (4) a jet of untreated air from the atmosphere was minimally effective.

Fenning, et al.,<sup>45</sup> found that ventilation of the tank crew compartment presents a unique problem in that the volume of space allocated per man is quite small. The high concentrations of gas fumes present within the tank, as well as the possibility of high concentrations of dust being drawn into the compartment, complicated the problem. They found nothing in the literature which appeared useful in designing a ventilation system for tanks which met current stipulations. At that time, the Office of the Surgeon General recommended a ventilation rate of 250 CFM per man, but Fenning, et al., found no research to back up this figure.

Some of the parts of the body are more sensitive to air currents. Velocities which are much above the threshold value of air current perceptibility may cause discomfort. In the limited space of the tank crew compartment, difficulties may be expected in reconciling the volume of air which must be moved while maintaining reasonable air velocities.

Fenning, et al.,<sup>46</sup> in recommending the objectives for design of a tank ventilation system, stated that attempts should be made to keep air velocities below 100 feet per minute with the definite specification that

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<sup>45</sup>W. Fenning, P. Jackson, and R. Kelley, *op. cit.* 1954.

<sup>46</sup>*Ibid.*

air currents which exceed that velocity be directed away from the sensitive portions of the body. These researchers also felt that research should be conducted in an effort to establish ventilation standards and that the effects of ventilation on the concentrations of dust to be expected in the compartment should be considered.

Eichna, et al.,<sup>47</sup> conducted a field test to determine the relative merits of three chemical protective systems. The three systems were: (1) a completely self-contained protective pressure ventilation system; (2) individual ventilated face masks with air supplied from a central blower system; and (3) regular Army issue chemical protective mask. They reported that from the standpoint of comfort the self-contained system and the ventilated face mask were preferred to the standard mask. The chemical protective clothing did not have to be worn with Method 1 as long as the tank protective system was operating properly. With Methods 2 and 3, the crew had to wear chemical protective clothing at all times. The ventilated facepiece with an air flow of 6.0 CFM was strongly disliked, due to the hot air being drawn in from the outside. The test was conducted at Fort Polk, Louisiana, with temperatures ranging from 88°F to 103°F (DBT). The tank with the self-purified air produced a positive pressure of three-quarters of an inch.

It was discovered that perspiration rates, rectal temperatures, and heart rate were somewhat higher when the tanks were moving slowly than when moving fast. The differences were small and deemed not to be of any practical importance. Air flow rates in stationary tanks were 300-400 CFM as compared to 1200-1500 CFM for moving tanks.

<sup>47</sup>L. Eichna, R. Walpole, W. Shelley, and J. Whittenberg. *Effects Upon Tank Crews of Several Methods of Protection Against Chemical Warfare Agents*, Project No. 35, Armored Medical Research Laboratory, Fort Knox, Kentucky, September 1944.

The physiological changes reported by Eichna and his coworkers were greatest in the driver; this was true for both the unprotected crew in regulation fatigue clothing and for the crews with the combat mask or the ventilated facepiece. Drivers lost twice as much liquid as crewmen in the turret and their rectal temperatures were 1.0-1.5°F higher. They also exhibited higher pulse rates (25-30 beats/minute faster). In the totally protected, positive-pressure ventilated tank, the situation reversed itself with the turret crewmen showing more physiological changes than the drivers. The total protective system with a ventilation rate of 275 CFM imposed a slightly greater load (regarding perspiration rates, rectal temperatures, and heart rates) than the individual combat mask or the ventilated facepiece system. However, based on the physiological changes induced, the differences between all three systems were not sufficiently great to select one method over another. Of the three protective systems, the tank commanders preferred the ventilated facepiece. Gunners preferred the total protective system. Loaders and drivers seemed to prefer the ventilated facepiece.

#### Miscellaneous Environmental Effects

Fenning, et al.,<sup>48</sup> briefly discuss the effects of thermal radiation between the vehicle walls of a tank and the human body. Since the turret compartment steel walls are uninsulated and in direct contact with the outside atmosphere, the temperature on the interior face of these walls will be substantially the same as that on the exterior face. If the temperature of the metal surround is much different from that of the intervening

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<sup>48</sup>W. Fenning, P. Jackson, and R. Kelley, *op. cit.*, 1954.

air, then heat will radiate from the warmer mass to the colder. Fanning and his associates recommend a study of these effects, as they feel they may contribute significantly to the comfort/discomfort of tank crewmen. In the direct summer sun, the temperature of the tank chassis may greatly exceed the ambient air temperature and add substantially to the internal temperature. Absorption of this radiated heat may also directly increase the body temperature of the crewmen. Conversely, cold thermal radiation from the human body to the tank chassis may result in greater than expected heat losses.

In a study conducted at Yuma Proving Ground, Suarez<sup>49</sup> determined the upper temperature ranges for critical components of the M60 tank under desert storage and operational conditions. He found that the Wet Bulb Globe Temperature (WBGT) during the days of the test with the vehicle moving was never below 100°F and reached 106.6°F. The tanks only carried a driver and a data collector, so with a full crew the conditions within the tank would probably have been worse. The conclusions from this study were:

1. The WBGT in the crew compartment is much higher than is commonly acceptable as working conditions for humans.
2. Surface temperatures of areas which the crew may contact are high enough (up to 155°F for the test) to cause extreme discomfort or blistering of the skin.
3. AR 70-38 (*Test and Evaluation of Material for Extreme Climatic Conditions*, 5 May 1969) design criteria are inadequate when used alone to predict interior temperature for M60 tanks operating in a desert environment.

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<sup>49</sup>J. Suarez. *Methodology Investigation of Armored Fighting Vehicle Compartment Temperatures, M60 Tank*, USAFG Report No. 203, US Army Yuma Proving Ground, Arizona, November 1974.

The significance of Suarez' second conclusion (finding) to the work of Fenning and his coworkers on heat radiation effects is obvious. If tank surface temperatures reach 155°F, radiation of heat to the occupants is bound to be substantial. These effects will add to the already deleterious effects of wall heat on the internal atmosphere of the compartment.

Eichna, et al.,<sup>50</sup> (researchers at the Armored Medical Research Laboratory) investigated the work rates of tank crew members for various tasks. This investigation was undertaken to study two major problems: (1) crew fatigue which was observed under virtually all operating conditions, and (2) the lowering of efficiency and morale and the occurrence of heat exhaustion among crews operating in tropical climates. The investigators found that work rates were often a cause of crew fatigue, particularly when combined with the many other adverse conditions which may occur in tank warfare. Maintenance and servicing, which took approximately two hours nightly, expended energy equivalent to a seven-mile march in the same period (based on an average figure of 350 calories per hour, per man for two hours). They also found that a single crew member, operating near the upper limits of thermal tolerance, may require two quarts of water per hour, or an entire crew may need ten or more gallons for four hours of operation. The requirement for liquids was mentioned in the earlier section dealing with the general effects of high ambient temperatures. However, in this study, Eichna and his associates related this requirement not only to temperature, but to the level of activity engaged in by tank crewmen specifically.

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<sup>50</sup>L. Eichna, et al., *op. cit.*, 1945.

Similar results were reported by Adolph and Dill.<sup>51</sup> They found that the daily intake in water in the desert was 10 to 30 times the daily variation in body weight. These authors also mentioned that sealing a vehicle for protection against noxious substances and for fording diminishes ventilation and accentuates the problem of heat load.

These data provide some perspectives on the actual total volume of liquid that must be carried inside a tank during buttoned-up operations during extremes of heat. During an eight-hour operation, 20 gallons or more may be required. Neither space nor containers for this volume of liquid are available in our current vehicles.

#### Summary and Implications

When a task is not hazardous and demanding, and the individual is well-insulated, the limiting factor in cold tolerance appears to be the temperature of the individual's extremities. Performance starts to deteriorate, especially in tasks requiring manual dexterity, when the hands are exposed to temperatures below 60°F. At temperatures below 20°-25°F, it is almost impossible to maintain the fingers at temperatures adequate to perform tasks requiring fine manual dexterity. In tanks, it has been suggested that warm air could be directed over critical controls, such as the gunner's traversing and elevating controls or the driver's steering controls, in order to maintain hand skin temperatures above 60°F.

During low ambient temperatures the inside temperature of the tank should be maintained at a minimum of 20°F and a maximum of 25°F. The minimum figure results from the desirability of maintaining warmth with

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<sup>51</sup>E. Adolph and D. Dill. "Observations on Water Measurement in the Desert," *American Journal of Physiology*, 1938, 123, 369.

with as little bulkiness of clothing as possible. If a satisfactory means of protecting the extremities could be found, performance could be maintained at lower ambient temperatures. The maximum of 25°F is suggested as a fuel conservation measure. Also, crewmen dressed for 25°F can withstand much lower temperatures for a time if forced to dismount.

Under high ambient temperature conditions, the critical level for effective performance seems to be around 90°F. Performance above this temperature deteriorates rapidly. The optimum temperature seems to be about 70°F, with performance declining either above or below. Cold generally results in a more rapid deterioration of performance than heat. Acclimatization to cold is usually achieved in one week and to heat usually within three to 12 days.

The comfort range for humidity seems to be between 40 and 60 percent; change in either direction may bring about decrements in performance related to the magnitude of the change. Within ordinary temperature ranges, the cooling or warming effects of air flow are not influenced substantially by changes in humidity.

To operate in a buttoned-up mode, it is mandatory that tanks be equipped with some means of washing and/or wiping of optical devices to combat the effects of condensation accumulating on the inside or outside of optical devices during conditions of high humidity.

It has been shown that the accumulation of condensation on the inside of Armored Personnel Carriers (APCs) causes equipment stored inside of the APCs to become wet and also causes rust and crew discomfort.

Ventilation of the tank crew compartment presents a unique problem in that the volume of space allocated per man is quite small. The high

concentrations of fumes and dust being drawn into the tank compartment complicate the problem.

Research on the requirements for ventilation during periods of buttoned-up operations should be investigated, especially in operations under dusty conditions and high ambient temperatures.

Studies completed at Yuma Proving Ground under high ambient temperature conditions indicate that temperatures inside the M60 tank may reach levels unsuitable for human operations, even with the hatch open. These studies did not investigate the effects of closed-hatch operations which would undoubtedly further increase internal temperature.

Present tanks are not equipped to store water internally. Water is usually carried in five-gallon cans on the outside turret bustle racks. If buttoned-up operations for extended periods of time are envisioned, a built-in water storage system seems to be mandatory. Dehydration is probably the most serious physiological problem confronting armor crewmen operating in high ambient temperatures. A crew may need ten or more gallons for four hours of operation while operating near the upper limits of thermal tolerance.

### Confinement

Studies of isolation and/or confinement have varied from those in which subjects were individually isolated, immobilized, and sensorially deprived, to those in which groups were isolated in a limited physical space, but were otherwise unrestricted. Depending upon the circumstances, subjective symptoms reported include sleep disturbance, restlessness, inability to concentrate, fatigue, muscular weakness and soreness, boredom, monotony, feelings of dirtiness, headaches, dizziness, psychomotor

reactions, apathy, low morale, time disorientation, frustration, anxiety, irritability, hostility, displaced aggression, depression, and withdrawal.

However, not all of these studies are relevant to the present problem. First of all, the total length of time the crew of an armored vehicle can remain isolated and confined is limited by their ability to carry on board supplies of food, water, ammunition, fuel and other necessities. At present, this can be a few days at most. Nevertheless, three factors typically reported as being disconcerting to confined and/or isolated subjects are present, to varying degrees, in buttoned-up armor operations. The first is a sensory restriction in which the variation of environmental stimulation is reduced. Certainly, crewmen are not sensorially deprived, as noise and physical buffeting from movement may approach unbearable levels. However, the kinds of sensory inputs are greatly restricted compared to a normal environment.

The second factor is the restricted mobility of the crew due to space or clothing restrictions. The third factor concerns the effects of social isolation and social deprivation.<sup>52</sup> This latter factor becomes salient when radio silence is maintained, or when contact with higher command echelons is done only through radio communications, and the closed hatches prevent the normal face-to-face relationships with other tank crews.

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<sup>52</sup> Some may not agree that the isolation and deprivation experienced by tank crews fits the commonly accepted meaning of these terms. For example, Sells and Rawls (S. Sells and J. Rawls. *Effects of Isolation on Man's Performance*, USI 20, Bioengineering and Cabin Ecology, Science and Technology Series, American Astronautical Society, Tarzana, California, 1969) define social isolation as "...an effect of the state of isolation rather than of remoteness per se and often occurs even in centers of busy social activity.... Apparently, familiarity and dependence on the familiar for support are essential for adjustment, and remoteness is involved only as it is associated with deprivation. There are, of course, extreme individual differences in dependence and choice of dependency objects." They define social deprivation as "...separation from any significant

supports, which may include significant persons and role partners in family, work, and social relationships, as well as statuses, activities, objects, and surrounds on which the individual has learned to depend for feelings of well-being and security. The general hypothesis is that such separation is a source of stress to the individual to the extent that the present situation calls for modes of personal problem-solving that are not available and for which suitable alternatives cannot be found." It is certainly true that tank crewmen are not entirely separated from familiar physical surroundings while operating with closed hatches. Nor do they undergo any change in status or in individuals found in their immediate working environment. However, some changes do occur. Furthermore, what is most important is how the crewmen feel about the situation. If they feel isolated and socially deprived, some adverse psychological consequences can be expected. In any case, they are definitely more confined and isolated from a number of their normal sensory inputs.

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Certainly, it is obvious that buttoned-up operations will be confining in nature. Therefore, the remainder of this section will be devoted to the psychological effects of confinement and its effects on performance, especially of tasks similar to or actually performed by crewmen, either during or following confinement.

#### Physical Confinement (Psychological Effects)

Haythorn,<sup>53</sup> in experimental studies of small groups in confinement, observed that the rate of interpersonal information exchange was accelerated in the early stages of confinement. He noted further that difficulty resulted from such speeded acquaintanceship. Information interchange typically exceeded the rate at which an individual could learn to accept the idiosyncracies of another person, or, to cope with values markedly different from his own. Under these circumstances, individuals capable of controlling their aggressive impulses had a tendency to withdraw, which resulted in a

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<sup>53</sup>W. Haythorn. "Social Emotional Considerations in Confined Groups," in *The Effects of Confinement on Long Duration Manned Space Flights*, Proceedings of the NASA Symposium, 1966, pp 8-15.

breakdown of communications. Individuals began to guard their personal possessions and establish territorial rights which were zealously guarded. Sells and Rawls<sup>54</sup> reported that Altman and Haythorn,<sup>55</sup> and Cowan and Strickland,<sup>56</sup> both reported that territorial behavior occurred earlier and more extensively among their isolated experimental subjects than among controls, and that it increased with time.

It has been reported that status leveling is a frequently observed occurrence in groups that are both isolated and confined.<sup>57,58,59,60,61,62</sup>

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<sup>54</sup>S. Sells and J. Rawls. *Effects of Isolation on Man's Performance*, USI 20, Bioengineering and Cabin Ecology, Science and Technology Series, American Astronautical Society, Tarzana, California, 1969.

<sup>55</sup>I. Altman and W. Haythorn. "The Ecology of Isolated Groups," *Behavioral Science*, 1967, 12, 169-182.

<sup>56</sup>E. Cowan and D. Strickland. *The Legal Structure of a Confined Micro-society (A Report on the Cases of Penthouse II and III)*, Internal Working Paper No. 34, Space Sciences Laboratory, Social Sciences Project, University of California, Berkeley, August 1965.

<sup>57</sup>P. Torrance. "Leadership in the Survival of Small Isolated Groups," in *Symposium on Preventive and Social Psychiatry*, Walter Reed Army Institute of Research, Washington, D.C., 1957, pp 309-327 (a).

<sup>58</sup>P. Torrance. "What Happens to the Sociometric Structure of Small Groups in Emergencies and Extreme Conditions?" *Group Psychotherapy*, 1957, 10, 212-220.

<sup>59</sup>J. Rohrer. *Studies of Human Adjustment to Submarine Isolation and Implications of Those Studies for Living in Fallout Shelter*, Working Paper, Disaster Research Group, Division of Anthropology and Psychology, National Academy of Sciences-National Research Council, Washington, D.C., 1959.

<sup>60</sup>S. Sells. *Tapescript to Accompany Tape Recording of Research Report on Leadership and Organizational Factors at Effective AC&W Sites*, AF Contract No. 41(657)-323, Institute of Behavioral Research, Texas Christian University, Fort Worth, October 1963.

<sup>61</sup>S. Sells. *Capsule Society. New Problems for Men in Space on Long-Duration Missions*, presented at the Conference on Bioastronautics, Virginia Polytechnic Institute, Blacksburg, Virginia, August 1967.

<sup>62</sup>W. Wilkins. "Group Behavior in Long-Term Isolation," in M. Appley and R. Trumbull (eds.), *Psychological Stress*, New York: Appleton-Century-Crofts, 1967.

The close association and lack of personal privacy characteristic of groups confined in small areas tend to equalize or "level" the social status of all the occupants. This would make it difficult to maintain superior/subordinate relationships when absolute discipline is required for mission accomplishment. In combat, the tank commander must be able to exercise absolute authority during critical periods. Therefore, status leveling could become a problem in situations requiring frequent and extended periods of operations in a buttoned-up mode.

Another tendency in isolated groups is to direct anger, scorn, and even ridicule, with an intensity often out of proportion to the focal issue, on external competitors and superior authorities.<sup>63</sup> Commanders must realize the existence of this problem, and develop means of coping with it effectively. Research in this area is obviously needed, as means of handling this displaced aggression are yet to be devised. How much of a problem this might become in armored operations is not known.

The term *claustrophobia* is well known to the American public. However, the US Navy is apparently the only branch of the military to be concerned about this type of fear. The submarine service has attempted to find practical techniques to assess and detect individuals with sub-clinical claustrophobic tendencies prior to exposure to confinement. The Escape Training Tank serves as a device for revealing these tendencies to the medical officer's attention. A similar type of training device that armor might be able to use for screening claustrophobic-prone individuals is an underwater driving course which would be monitored by TV cameras. Thus, the individuals could be observed performing in a confined environment.

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<sup>63</sup>S. Sells, and J. Rawls, *op. cit.*, 1969.

A study of claustrophobic reactions by Kinsey and Murphree<sup>64</sup> found that neither simple screening methods nor Rorschach testing was effective in detecting individuals with sub-clinical claustrophobic tendencies. The subjects in the study later exhibited phobic responses which were apparently precipitated or aggravated by stresses encountered in the submarine service.

Kinsey and Murphree reported three variant reactions: (1) about half of the subjects were previously aware of their condition, but entered the submarine service anyway and, after doing so, could not tolerate the resulting discomfort; (2) others were totally unaware of their claustrophobic tendencies until they suffered the onset of acute symptoms; and (3) still others appeared to be chronically anxious individuals who, in the face of unusual stress, unconsciously used the symptom to temporarily extricate themselves from the situation. It was determined that volunteers for hazardous or unusual duty may have been motivated to volunteer because of individual needs of which they were not necessarily aware.

In summary, Kinsey and Murphree found that claustrophobia, as a broad concept, is a symptom or symptom-complex which can occur in individuals of diverse personality structure and in response to varied needs. It does, however, seem more likely to appear in individuals who habitually utilize hysteric character defenses. They, therefore, concluded that it is not likely that individuals with sub-clinical claustrophobic tendencies can be detected until a stressful situation has provoked symptoms or until the individual voluntarily seeks psychiatric help.

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<sup>64</sup>J. Kinsey and H. Murphree. *Claustrophobic Reactions to Some Stresses of the Submarine Service*, MRL Report No. 262, vol 24, no. 2, Medical Research Lab, US Naval Submarine Base, New London, Connecticut, April 1955.

Whitney<sup>65</sup> encapsulated eight experienced tank crewmen in each of four experimental work spaces for 24 hours. The sitting posture for the different spaces ranged from reclining to fully upright. Each experiment included psychological and detailed physiological testing. No instances of severely adverse symptoms associated with the experimental condition were found. It was concluded that the crew spaces used provided appropriate space for crew accommodations for prolonged occupation. It should be noted that this was a laboratory study and individuals were not required to perform any tasks; occupation of the vehicle for 24 hours only was investigated.

While peculiarities in behavior have been observed under conditions of confinement, the literature reviewed did not indicate that confinement alone would result in any gross personality disturbances. Bizarre personality manifestations are reported primarily in the literature of extreme sensory deprivation, and was not cited here as it did not seem relevant. Sells and Rawls,<sup>66</sup> in their review of the literature, also observed that the consequences of confinement need not necessarily be severe. They state:

... On the other hand, in situations involving trained, disciplined personnel and in the absence of major disorganizing forces of disaster, the occurrence of serious overt interpersonal conflict, deterioration of interpersonal behavior and group disorganization, frequently mentioned in the anecdotal literature has been rare.

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<sup>65</sup> Whitney. *Fighting Vehicle Research Capsule Investigation*, APRC-71/ RVI Army Personnel Research Committee, September 1971.

<sup>66</sup> S. Sells and J. Rawls, *op. cit.*, 1969.

### Performance During/After Confinement

In a study by Hauty,<sup>67</sup> subjects were confined in a simulated space cabin for seven days and performed several tasks on a four hour on/four hour off work/rest cycle. Performance of radar monitoring and vigilance tasks declined, while performance of discrimination and problem-solving tasks showed little decrement. In a study by Ormiston,<sup>68</sup> subjects confined individually in a small capsule for 48 hours showed a decrement in performance on an aerial reconnaissance task, but not on cognitive measures such as perceptual speed and accuracy, form discrimination, or light monitoring tasks. In another study by Ormiston,<sup>69</sup> subjects confined individually in a small cubicle for eight hours showed no differences on tracking, monitoring, or time estimation tasks when compared to subjects who were not confined.

Flinn, et al.,<sup>70</sup> reported that subjects confined in a two-man cabin simulator for 30 days were able to maintain adequate performance and morale, despite the occurrence of some personal resentment. In a study by Hartman, et al.,<sup>71</sup> four pairs of subjects participated in a simulated

<sup>67</sup>G. Hauty. "Psychological Problems of Space Flight," in O. Benson, Jr., and H. Streshold (eds.), *Physics and Medicine of the Atmosphere and Space*, New York: John Wiley, 1950, pp 409-421.

<sup>68</sup>D. Ormiston. *The Effects of Confinement on Intellectual and Perceptual Functioning*, ASD Technical Report 61-577, Aeronautical Systems Division, Wright-Patterson AFB, Ohio, 1961.

<sup>69</sup>D. Ormiston. *A Methodological Study of Confinement*, WADC Technical Report 61-258, Wright Air Development Command, Wright-Patterson AFB, Ohio, 1961.

<sup>70</sup>D. Flinn, J. Monroe, Jr., E. Cramer, and D. Dager. "Observations in the SAM Two-Man Space Cabin Simulator. IV. Behavioral Factors in Selection and Performance," *Aerospace Medicine*, 1962, 33, 610-615.

<sup>71</sup>B. Hartman, B. Welch, and K. McKenzie. "Performance Effects in 27-Day Simulated Space Flights," *Aerospace Medicine*, 1967, 38, 1098-1102.

17-day space flight. Their performance on a series of psychomotor tasks was found to be unrelated to length of work day, day versus night, or duration of flight. In a study by Hanna and Gaito,<sup>72</sup> naval enlisted men were confined under simulated flight conditions for seven days. Their subjects showed no deterioration of psychomotor or intellectual functions, even though the confinement conditions were less than optimal.

All of the above studies were cited in Cannon, Drucker, and Keseler,<sup>73</sup> which is one of the few sources I found that made an attempt to ascertain what information was available in the literature on armor operations over extended periods of time.

Hicks,<sup>74</sup> in a series of studies, investigated the effects of confinement on riflemen's performance in combat relevant tasks following periods of confinement in APCs. In particular, subjects were confined for periods of four, eight, 12, or 24 hours. Stamina, equilibrium, hand-arm steadiness, and eye-arm coordination were all found to be adversely affected. For example, in Hicks' four-hour study,<sup>75</sup> there was a significant loss in rifle firing accuracy, a loss of both stamina and gross motor coordination, and disturbances of equilibrium.

Further, Hicks found, for repeated confinement of subjects acclimatized to a hot-wet environment in Panama, that the greatest decrement in

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<sup>72</sup>T. Hanna and J. Gaito. "Performance and Habitability Aspects of Extended Confinement in Sealed Cabins," *Aerospace Medicine*, 1960, 31, 399-406.

<sup>73</sup>D. Cannon, E. Drucker, and T. Kessler. *Summary of Literature Review on Extended Operations*, HUMRRO Consulting Report, Human Resources Research Organization, Alexandria, Virginia, December 1964.

<sup>74</sup>S. Hicks, *op. cit.*, 1964.

<sup>75</sup>S. Hicks. *The Effects of Four Hours Confinement in Mobile Armored Personnel Carriers on Selected Combat Relevant Skills: A Pilot Study*, Technical Memorandum 3-60, US Army Human Engineering Laboratories, Aberdeen Proving Ground, Maryland, 1960.

performance occurred after the first period of confinement.<sup>76</sup> Increasing confinement time and/or decreasing ventilation further did not decrease performance. These observations suggest an adaptation phenomenon which allows the subjects to adjust to the environment while still maintaining an acceptable level of performance. In this study, an acceptable performance level was defined as performance which did not differ significantly from pre-confinement practice levels.

In a summary of his results, Hicks pointed out that several identifiable factors contributed to the observed performance decrements. The most obvious was the extreme movement limitation imposed by the working space and the resulting loss of circulation in the lower body. The rims on the bucket seats and the backrests caused a great deal of discomfort, particularly when riding over rough terrain. A lack of adequate stowage space also presented a problem. Equipment had to be stowed in the aisle, further restricting movement and increasing the cramping of crew members. With longer stays in the vehicle, equipment became more and more a nuisance as it shifted about and cluttered the floor.

#### Summary and Implications

Relevant studies have shown no serious or severe psychological or physiological symptoms resulting from relatively short times of confinement likely to be encountered in armored vehicles. The discomfort from confinement in armored vehicles is basically a physical restriction due to the limited space available. Loss of gross motor coordination after

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<sup>76</sup>S. Hicks. *The Effects of Repeated Confinement on the Performance of Men in a Hot-Wet Environment*, Technical Memorandum 7-63, US Army Human Engineering Laboratories, Aberdeen Proving Ground, Maryland, January 1963.

short confinement has been observed and could become serious if the crew were to have to dismount and seek safety or engage in ground combat without readjustment time.

The most obvious factor which contributes to performance degradation is the extreme limitation on bodily movement which is imposed by the vehicle configuration and the resulting loss of circulation in the lower body. Although not specifically mentioned as a problem in the research reviewed, the restriction of the visual area imposed on the crew during buttoned-up conditions should be investigated for its effects on target detection and acquisition.

It may well be that performance during and following buttoned-up operations in the future will be quite different from that shown in the few previous studies reviewed. Crew members in these studies operated under less than ideal circumstances and in vehicles not designed for operating under conditions of prolonged occupancy. Training for armor crews has rarely emphasized closed-hatch operations and, if done at all, was intended to cover operations for short periods of time only, usually when it was necessary to obtain protection against overhead artillery. Better vehicle design, coupled with appropriate training, may completely counter any undesirable effects of short-term confinement.

### Combat Stress

There are a number of factors in the total environment which interfere with adjustment and are generally accepted as being stressful. Among factors which have been cited as occurring in natural settings or employed as stressors in laboratory situations are such varied things as physical danger (threat of injury or death), fatigue, isolation, sensory

deprivation, confinement, crowding, personality incompatibility, lack of privacy, noise, vibration, heat, cold, hunger, thirst, monotony, and fear of failure. Although it has been proposed that arousal resulting from moderate levels of stress (particularly physical threat) may facilitate performance, the degradation of performance under extreme or prolonged stress is not questioned.

Many of the stressors listed in the paragraph above are likely to apply at some time or another to tank crewmen during buttoned-up operations. In fact, several stressors are likely to be acting in conjunction. Those most applicable to the buttoned-up situation are discussed as separate sections of this report (e.g., heat, cold, vibration, and noise). However, the soldier, by virtue of his chosen profession, may also face the threat of imminent physical injury or death during combat. This threat is probably the greatest and most consistent stressor he must cope with, and is the subject of this section.

The nature of the relationship between combat stress and performance is not well understood. Little success has been had in attempts to predict individual reactions to stress. Relationships discovered in one population or one time or one situation have not been generalizable to other settings.

Helmreich<sup>77</sup> stated that:

In laboratory settings where conditions are less extreme than those in real life settings, investigators know the high frequencies of failure [of subjects] to complete studies because of excessive emotional strain, large decrements in performance, and profound interpersonal

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<sup>77</sup> R. Helmreich. *Human Reactions to Psychological Stress: Stress, Self-Esteem, and Attitudes*, Technical Report No. 12, Department of Psychology, University of Texas, Austin, November 1970.

conflict. In contrast, successful confrontations with extreme stress have been noted in combat, exploration parties, paratroop training, and saturation diving. In other words, a projection from laboratory to simulation studies of environmental stress would lead to the patently false prediction that humans could not successfully tolerate the high stress found in natural settings.

One of the major conclusions reached by a fatigue and stress symposium conducted by the Operations Research Office, Johns Hopkins University, in 1952<sup>78</sup> was the the "present knowledge of the fundamental mechanisms of fatigue and stress is inadequate to define the degree of impairment, establish permissible limits of deterioration, predict imminence of complete collapse, and describe the interrelation of stresses and tolerance limits under varying conditions." This panel recommended that data from actual combat conditions be used to study fatigue and stress.

A useful definition of *combat degradation* was presented in a report by Walker and DeSocio.<sup>79</sup>

Combat degradation means any reduction in performance of a system using human operators which is associated in any way with the performance of the operators, and is measured by the ratio of the error measured in combat to the errors in some peacetime condition. It does not include any lack of reliability of the system or any failure in performance of inanimate components. It may be due to any factor affecting the operator, such as inadequate briefing, difficulty of recognizing targets, enemy evasive maneuver, as well as to combat stress, and it can be reduced by "motivation."

Obviously, what Walker and DeSocio refer to as combat degradation is not equivalent to the complete psychiatric breakdown often reported during long and intense combat. However, it serves as a reminder that performance

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<sup>78</sup>Fatigue and Stress Symposium, 24-26 January 1952. Operations Research Office, Johns Hopkins University, Chevy Chase, Maryland.

<sup>79</sup>N. Walker and E. DeSocio. *The Effect of Combat on the Accuracy of Various Human Operator Control Systems*, Report No. 9, Norman K. Walker Associates, Inc., Bethesda, Maryland, April 1964.

can be degraded by the stresses of combat without the affected individuals becoming casualties.

Mitchell, Walker, and Meiland<sup>80</sup> attempted to correlate performance in combat and performance in particular artificial stress situations. One sample was composed of 305 infantrymen in Korea and the other of 120 trainees at Fort Ord, California. The artificial combat stress situations used were the mock parachute jump, electric shock, and firefighting. The correlation between the artificial stress test scores and combat performance data were too low to allow use of the artificial test situation as an indicator of stress tolerance.

As mentioned earlier, the nature of the relationship between combat stress and performance is not known. Stouffer, et al.,<sup>81</sup> as reported by Schultz,<sup>82</sup> identified (in their extensive studies of World War II combat) types of stress which serve to weaken man physically and psychologically. Some of these stresses include: (1) prolonged frontline duty with its ever-present threats to life and limb; (2) extreme physical discomfort, including extremes of temperature, inadequate food, water, clothing, shelter, lack of sleep, insects, filth, fatigue, etc.; (3) anxiety engendered from a death or wounding of close friends and a constant exposure to the wounded and dying; and (4) deprivation of the usual sources of affection and security. Garner,<sup>83</sup> as reported by Schultz,

<sup>80</sup>M. Mitchell, G. Walker, and T. Meiland. *Inferred Correlation Between Combat Performance and Some Field Laboratory Stresses*, HUMRRO Memorandum, Human Research Unit, Fort Ord, California, November 1958.

<sup>81</sup>S. Stouffer, et al. *The American Soldier: Combat and Its Aftermath* (Vol 2), New York: Wiley and Sons, 1949.

<sup>82</sup>D. Schultz. *Panic Behavior*, New York: Random House, 1964.

<sup>83</sup>H. Garner. "Psychiatric Casualties in Combat," *War Medicine*, 1945, 8 343-357.

suggested that anything which reduced the soldier's morale, such as loss of confidence in his leaders, could also predispose feelings of panic. Schultz<sup>84</sup> notes that when a soldier is cut off from his usual sources of affection, security, and status, he turns more and more to his military primary group for satisfaction of his basic emotional needs. When this sense of group identity and belonging is disrupted by too many casualties or replacements, or when personnel do not have sufficient opportunity to even develop this group identity, they are less able to resist the stresses of battle and are more predisposed to behave as individuals and to be concerned with self-survival rather than with survival of the group as a whole.

Several studies of statistical records have shown that there is a higher rate of psychiatric casualties among soldiers during combat than during non-combat,<sup>85,86</sup> as reported in Cannon, *et al.*<sup>87</sup> Other records show that when units remain in contact with the enemy during combat, regardless of whether it is moderate or heavy, offensive or defensive combat, there is a disproportionate increase in the number of psychiatric casualties as compared to the number of wounded after four days.<sup>88</sup> This was not the case, however, for units advancing against little or no

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<sup>84</sup>D. Schultz, *op. cit.*, 1964.

<sup>85</sup>J. Sagebiel and L. Bird. "Study of Psychiatric Casualties Received at US Naval Base Hospital From the Solomon Island Battle Area," *Navy Medical Bulletin*, 1943, 41, 1629-1637 (Psychological Abstract, 18:504).

<sup>86</sup>J. Marren. "Psychiatric Problems in Troops in Korea During and Following Combat," *US Armed Forces Medical Journal*, 1956, 7, 715-726.

<sup>87</sup>D. Cannon, E. Drucker and T. Kessler, *op. cit.*, 1964.

<sup>88</sup>F. Hanson (ed.). "Combat Psychiatry: Experiences in the North African and Mediterranean Theaters of Operation, American Ground Forces, WWII," *The Bulletin of the USA Medical Department*, 1949, 9.

opposition. There is little question but that the longer men are in combat, the more likely they are to become victims of combat exhaustion. Records of men in the Normandy Assault<sup>89</sup> indicated that men adjusted to combat in five to seven days, reached peak efficiency in 21 days, and maintained this efficiency for about one week. After about 30 days, the first signs of combat exhaustion (stomach disturbances, extreme irritability, loss of confidence, fatigue, unrelieved by rest up to 48 hours) began to appear.

In the 4th Armored Division, ten weeks in combat was apparently the breaking point for many men, as reported in a study by Mericle.<sup>90</sup> Mericle also reported that having a tank "shot out from under them" two times was the limit for most men. Combat exhaustion symptoms were extremely likely if a third tank was destroyed by enemy action.

Various estimates have been given for the length of time troops should be left in combat. These range from 120 to 200 days.<sup>91</sup> Based on casualty rates in Italy, a goal of 120 days was set. Beede and Apple<sup>92</sup> analyzed 2500 World War II (WWII) infantrymen with high-risk assignments to determine the capacity of US infantrymen to withstand stress without breaking down psychologically. They reported the probability of becoming

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<sup>89</sup>R. Swank and W. Marchand. "Combat Neuroses: Development of Combat Exhaustion," *Archives of Neurology and Psychiatry, Chicago*, 1946, 55, 236-247.

<sup>90</sup>E. Mericle. "The Psychiatric and the Tactical Situation in an Armored Division," *Bulletin of US Army Medical Department*, 1946, 6, 325-334.

<sup>91</sup>R. Swank. "Combat Exhaustion: A Descriptive and Statistical Analysis of Causes, Symptoms and Signs," *Journal of Nervous and Mental Disorders*, 1949, 109, 475-508.

<sup>92</sup>G. Beede and J. Apple. *Variation in Psychological Tolerance to Ground Combat in World War II*, Division of Medical Sciences, National Research Council, Washington, D.C., 1958.

a battle casualty to be a decreasing function of stress, and the probability of becoming a psychiatric casualty a rapidly increasing one. Beede and Apple also estimated that about half of the men would breakdown psychologically if subjected to more than 80 to 90 days of combat during which their company sustained casualties. The records of rifle companies in WWII showed that the average time requirement placed upon men in the Mediterrean theater was such as to exceed the breaking point of 45-50 percent of the men.

Davis and Taylor<sup>93</sup> studied the effects of combat stress during the Korean conflict. They found that "proportionately more time was required to recover physiological normalcy following intense combat than following less intense combat such as a holding defensive action...."

Berkun, et al.,<sup>94</sup> compared the behavior of combat-experienced troops and troops with Army experience (new recruits with up to but not more than four weeks of basic training) when faced with a perceived threat of injury or death. Although the subjects were not actually in danger, they found themselves in situations in which they thought that accidental circumstances placed them in the path of a forest fire, an artillery practice impact area, or in an area of heavy radioactive fallout. The inexperienced troops broke down more easily and were unable to help themselves, whereas the experienced troops took appropriate measures to deal with the situations.

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<sup>93</sup>S. Davis and J. Taylor. *Stress in Infantry Combat*, Technical Memo ORO-T-295, Johns Hopkins University, Chevy Chase, Maryland, September 1954.

<sup>94</sup>M. Berkun, H. Bialek, R. Kern, and K. Yagi. "Experimental Studies of Psychological Stress in Man," *Psychological Monographs*, 1962, 76, No. 15 (Whole No. 534).

Much anecdotal information is available on combat stress. However, it is virtually impossible to verify its validity. Also, anecdotes almost always deal with extreme cases. Therefore, taken at face value, they might well lead to expectations that cannot be fulfilled.<sup>95</sup>

Unfortunately, most of the data available on combat stress concerns either infantry, or is nonspecific regarding duty positions. No data concerning armor crewmen specifically was located. As a result, there are no indications as to whether armor crewmen are more or less prone to psychological breakdown than other soldiers.

Experimental studies of extreme or long-term stress are rare indeed. The ethics of stress research have always been questioned by some, and have become much more of an issue in recent years. As a result, the data which are available tend to come from the behavior of people during war-time or during and following natural disasters. The lack of control in such naturalistic observation makes evaluation of stress effects difficult under combat or other hazardous conditions.<sup>96</sup>

#### Summary and Implications

The literature on stress enumerates many problems involved in drawing comparisons between performance in laboratory studies and field studies. It is generally conceded that there is little correlation between performance in combat and performance in artificial stress situations. This naturally makes it difficult to conduct realistic research on stress tolerance to combat. Studies conducted concerning actual combat situations

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<sup>95</sup>D. Cannon, E. Drucker, and I. Kessler, *op. cit.*, 1964.

<sup>96</sup>W. Harris, R. Mackie, and C. Wilson. *Performance Under Stress: A Review and Critique of Recent Studies*, Technical Report VI, Human Factors Research, Inc., Goleta, California, July 1956.

indicate high casualty rates due to psychological breakdowns. The investigators agreed that there is a limit to man's capability to withstand combat stresses. However, estimates of how long men can remain in combat and still function effectively ranged from 30 to 200 days.

Few studies were uncovered by the literature search dealing directly with stress under buttoned-up conditions. Combat studies dealing with stress have been largely concerned with evaluating performance with infantry units. Similar research on the effects of combat on armor specialties specifically is needed.

### Noise

The effects of noise on the human organism can be classified as: (1) simple annoyance, (2) interference with verbal communication, (3) effects on psychophysical functioning, and (4) permanent hearing loss. Most of the criteria for noise limitation have been set to prevent permanent hearing losses. Design standards for Army materiel for this purpose are contained in Human Engineering Laboratory Standard (HEL STD) S-1-63B.<sup>97</sup> Hodge,<sup>98</sup> in his presentation to the Conference on Continuous Operations in 1971, felt that the best available Damage-Risk Criteria (DRC) for both steady-state and intermittent noise were those developed by the National Academy of Science/National Research Council (NAS/NRC).

<sup>97</sup> R. Chaillet and G. Garinther. *Maximum Noise Level for Army Materiel Command Equipment*, HEL-S-1-63B, US Army Human Engineering Laboratory, Aberdeen Proving Ground, Maryland, June 1965.

<sup>98</sup> D. Hodge. "Environmental Quality Considerations for Continuous Operations," in D. Hodge (ed.), *Military Requirements for Research of Continuous Operations, Proceedings of a Conference Held at Texas Tech University, Lubbock, Texas, 28-29 September 1971*, Technical Memorandum 12-72, US Army Human Engineering Laboratories, Aberdeen Proving Ground, Maryland, April 1972, pp 39-50.

Committee on Hearing, Bioacoustics, and Biomechanics (CHABA).<sup>99</sup> The National Institute of Occupational Safety and Health (NIOSH)<sup>100</sup> has also published a set of standards. However, this latter set may not be applicable to a military environment for two reasons. First of all, these standards are set for personnel working 40 hour weeks over a lifetime in a given situation. Military personnel rarely work in the same situation so consistently. Secondly, in a specific military setting, the cost of maintaining peacetime industrial standards may be so great as to force an acceptance of some amount of hearing loss to personnel. A tradeoff between desirable and achievable limits is often necessary. Also, in situations where noise levels are expected to exceed acceptable levels, the Army assumes that protective devices will be worn. Criteria for regular exposure to noise for periods exceeding eight hours have not been developed.

While agreement on standards is not perfect, disagreement is not great. In general, it is accepted that the upper limit for steady-state noise is in the vicinity of 90 decibels (dB). The upper limit for impact noise depends on the number of impacts received per unit time, but is in the area of 140 dB for relatively infrequent impacts. Occasional impact noise levels up to 160 dB are considered acceptable by the Army.

Military Standard (MIL-STD) 1472A<sup>101</sup> sets the Army standards for permissible noise levels for non-interference with speech. The acceptable

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<sup>99</sup>*Hazardous Exposure to Intermittent and Steady-State Noise.* Report of Working Group 46, NAS-NRC Committee on Hearing, Bioacoustics and Biomechanics (CHABA), Washington, D.C., January 1965.

<sup>100</sup>[Conference on] Noise Evaluation and Control, Temple Texas, 1975, presented by Texas A&M University, Occupational Health and Safety Institute.

<sup>101</sup>Military Standard 1472A. *Human Engineering Design Criteria for Military Systems*, Department of Defense, Washington, D.C., May 1970.

levels are, of course a function of the level of the speech communication.

There is a considerable body of research on the effects of noise. In general, the findings have been consistent. Therefore, in the sections that follow, only a few examples illustrating specific findings relevant to this research area will be cited.

### Effects on Hearing

The damage to hearing caused by noise is dependent upon the particular individual, the intensity of the noise, its spectral composition, and its duration. Hearing losses become greater under high intensity, long duration, and narrow band width noises.<sup>102</sup> Hearing loss is also most rapid at the beginning of exposure.<sup>103</sup>

Subjects exposed to a loud continuous noise for 22 days over a 47-day period had their hearing measured after one, 12, and 90 days. The initial loss in the low frequency areas was small and showed a slow but steady recovery. Those who showed the greatest threshold shifts sustained the greatest permanent loss.<sup>104</sup>

Mills, et al.,<sup>105</sup> and Yuganov, et al.,<sup>106</sup> investigated the recovery from temporary threshold shifts in acuity after exposure to noise.

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<sup>102</sup>C. Morgan, J. Cook, A. Chapanis, and M. Lund, *op. cit.*, 1963.

<sup>103</sup>F. Berrien. *Relation of Noise to Habitability of Submarines. A Survey Report on Human Factors in Undersea Warfare*, National Research Council, Panel on Psychology and Physiology, Washington, D.C., 1949, pp 345-355.

<sup>104</sup>J. Fletcher and M. Loeb. *Changes in the Hearing of Personnel Exposed to High Intensity Continuous Noise*, USAMRL Report No. 566, US Army Medical Research Lab, Fort Knox, Kentucky, 1963.

<sup>105</sup>J. Mills, R. Gengel, C. Watson, and J. Miller. "Temporary Changes of the Auditory System Due to Exposure to Noise for One or Two Days," *Journal of the Acoustical Society of America*, 1970, 48, 524-530.

<sup>106</sup>Y. Yuganov, T. Krylov, and V. Kuznetsov. "Standard for Noise Levels in Cabins of Spacecraft During Long-Duration Flights," in V. Chernigovskiy, (ed.), *Problems in Space Biology. Vol. 7: Operational Activity, Problems in Habitability and Biotechnology*, Moscow: Nauka Press, 1967, 319-341 (Technical Translation F-529, National Aeronautics and Space Administration, Washington, D.C., May 1969).

They found that recovery took much longer when given shifts resulted from shorter exposures.

In a study of Army enlisted men exposed to aircraft noises, Senturia<sup>107</sup> found that 18.9 percent of the men tested showed elevations in thresholds of at least 15 dB for at least one frequency. Following exposure to flight and noise of 114 dB, subjects with 24 hours of rest showed recovery, while those with only one to eight hours of rest showed widespread hearing losses (as revealed by elevated thresholds).

It seems clear that exposure to intense sound levels produces at least a temporary shift in auditory acuity. Permanent damage may result if the intensity is too great or too prolonged. High intensity noise usually produces discomfort even when there is no effect on hearing.<sup>108</sup> Also, intermittent noise and high frequency sounds are typically judged more annoying than steady-state and low or medium frequency auditory stimuli. However, the subjective discomfort produced by these sounds may be more a function of their distracting properties than their effects on hearing.<sup>109</sup>

<sup>107</sup>B. Senturia. "The Influence of Airplane Noise on Auditory Thresholds," *Ann. Otol., etc., St. Louis*, 1953, 62, 331-349 (Psychological Abstracts, 29:3511).

<sup>108</sup>R. Plutchik. "The Effects on High Intensity Intermittent Sound on Performance, Feeling, and Physiology," *Psychological Bulletin*, 1959, 56, 133-151.

<sup>109</sup>C. Morgan, J. Cook, A. Chapanis, and M. Lund, *op. cit.*, 1963.

Whether any of these effects will be more severe in buttoned-up operations than in normal armored operations remains to be determined.

#### Noise Level in Armored Vehicles

Garinther and Blazie<sup>110</sup> obtained noise measurements in M60A1 tanks during four days of platoon-sized maneuvers. The average sound level of a tank during operation was 98.5 dBA in the turret and the sound level at the communications system earphone was about 104 dBA. This suggests that the primary cause of hearing damage among tank crews may be the high frequency noise levels produced at the ear by the communications system.

Stewart and Barrow<sup>111</sup> studied hearing loss in tank gunnery instructors. They developed hearing losses, first in the high tones and later in tones associated with normal speech. In another study on gunnery instructors, Machle<sup>112</sup> reported that with repeated exposures, hearing loss was similar to that observed in individuals who were exposed to sustained high levels of steady-state noise. Hearing loss was cumulative, but even after exposures of six to eight days, recovery occurred in a few days. Exposure to noise in the interior of the M114 armored command and reconnaissance (scout) vehicle for one hour resulted in temporary hearing loss, but a one-and-one-half hour rest period after exposure restored normal hearing.<sup>113</sup>

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<sup>110</sup>G. Garinther and D. Blazie. *Acoustical Evaluation of the M60A1 Tank During Typical Operations*, Technical Memo, US Army Human Engineering Laboratories, Aberdeen Proving Ground, Maryland, March 1973.

<sup>111</sup>J. Stewart and D. Barrow. "Concussion Deafness," *Archives of Otolaryngology, Chigao*, 1946, 44, 274-279.

<sup>112</sup>W. Machle. "The Effect of Gun Blast Upon Hearing," *Trans. Amer. Acad. Ophthal. Otolaryng.*, 1944-1945, 49, 90-96.

<sup>113</sup>G. Garinther. *Interior Noise Evaluation of the T114 Armored Command and Reconnaissance Vehicle*, Technical Memorandum 3-62, US Army Human Engineering Laboratories, Aberdeen Proving Ground, Maryland, 1962.

Wiegand<sup>114</sup> investigated hearing loss with German tank test drivers. Audiograms were obtained for 84 tank test drivers and 49 engine test bed operators. He found that the noise level in the crew compartment during movement was between 95 and 120 dB for German army tanks. He concluded that without protection, tank noise will cause rapid and permanent hearing loss. Even with protection, the reduction was not adequate, especially for the frequency range below 10-24 Hertz (Hz). Estimation of hearing loss was dependent on the method of measurement and the procedures used for evaluating hearing loss. Nevertheless, it was concluded that for noise with this spectral content and intensity, personal hearing protection will be of limited effectiveness. Measures for reduction of noise levels within these tanks must be taken mainly at the noise source itself.

#### Effects on Performance

Forshaw, Coffet, and Stong<sup>115</sup> conducted a noise survey of the Centurion tank used by Canadian forces. The results of the study indicated that drivers and crews of vehicles and certain instructors and weapon crews routinely exceed the limits prescribed by Canadian military standards. They concluded that more effective hearing protection devices and headsets were required for vehicle crews.

In a series of six studies on the effects of high intensity noise, Corso<sup>116</sup> found no deterioration in intelligence test performance, the

<sup>114</sup>D. Wiegand. *Hearing Loss Due to Tank Noise*, Library Translation 1748, Royal Aircraft Establishment, April 1974.

<sup>115</sup>S. Forshaw, C. Coffet, and R. Stong. *A Survey of Noise Hazards at the Combat Arms School, CFB,agetown*, DCIEM No. 814, Behavioral Sciences Division, Defence and Civil Institute of Environmental Medicine, Downsview, Ontario, Canada, September 1972.

<sup>116</sup>J. Corso. *The Effects of Noise on Human Behavior*, WADC Technical Report No. 53-81, Wright Air Development Command, Wright-Patterson AFB, Ohio, 1952.

retention of nonsense syllables, or the retention of meaningful verbal material. However, differences in pulse rate and pulse pressure identified people as to their susceptibility to noise.

Park and Payne<sup>117</sup> studied the performance of college men subjected to 98-108 dB noise levels. They found there was greater variability in performing simple and difficult division problems during intense noise, but no significant decrease in the number of correct solutions. Plutchik<sup>118</sup> found no effect of 105-122 dB noise levels on the time required on a mirror tracing task or on a compensatory tracking performance task. Subjects performing the Minnesota Clerical Test and the Revised Minnesota Form Board showed an increase in the number of attempted items and an increase in the number of correct items when subjected to sound bursts of 100 dB, but there was a drop in overall quality as indicated by an increase in the number of incorrect responses. The overall effects, however, were too small to be of practical concern.<sup>119</sup>

Azrin<sup>120</sup> studied 80 soldiers performing a temporal discrimination task. Adverse effects from changes in noise intensity were reported, but these effects were temporary and recovery occurred within 15 minutes.

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<sup>117</sup>J. Park and M. Payne, Jr. "Effects of Noise Level and Difficulty of Task in Performing Division," *Journal of Applied Psychology*, 1963, 47, 367-368.

<sup>118</sup>R. Plutchik. "Effect of High Intensity Intermittent Sound on Compensatory Tracking and Mirror Tracing," *Perceptual and Motor Skills*, 1961, 12, 187-194.

<sup>119</sup>K. Smith. "Intermittent Loud Noise and Mental Performance," *Science*, 1951, 114, 132-133.

<sup>120</sup>N. Azrin. *Some Effects of Noise on Human Behavior*, Technical Memorandum 6-58, US Army Human Engineering Laboratories, Aberdeen Proving Ground, Maryland, 1958.

Performance on a watchkeeping task (monitoring a display of steam-pressure gages) was impaired by a 100 dB noise when compared to performance under a 70 dB noise level. On an easier task, some subjects were affected by the noise, although all subjects became less effective with continued exposure.<sup>121</sup>

### Summary and Implications

There is good evidence that hearing is at least temporarily impaired by the noise levels which may be normally encountered in tanks. There is also evidence that continued exposure is likely to result in some permanent hearing loss. At best, the noise levels are likely to be annoying and distracting. However, there are no data which deal specifically with the differential effects of noise during buttoned-up operations compared to open-hatch operations. Two questions concerning noise which must be answered are: (a) Does closing the hatches increase the intensity of normal noises such as engine and road noises, and (b) is the impact noise from firing the main gun higher in intensity with the hatches closed? If the answers to these questions are negative, then it can be assumed that noise is no more of a problem in buttoned-up operations than in open-hatch operations. However, if the answer to either is affirmative, more research on the effects of noise will be necessary. Part of this research obviously should be concerned with protective devices.

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<sup>121</sup>D. Broadbent. "Some Effects of Noise on Visual Performance," *Quarterly Journal of Experimental Psychology*, 1954, 6, 1-5.

## Vibration

There are several indirect effects of motion on crew comfort. The most important of these is fatigue resulting either from the motion itself, or from the effort expended preventing tossing while attempting to maintain a satisfactory sitting position or in trying to perform necessary functions. Other physiological reactions, such as nausea and dizziness, may also contribute to crew discomfort. Sternick, Stimmel, and Sattinger,<sup>122</sup> in discussions with military personnel, discovered that many individuals have a strong fear of being injured by violent motions that could throw a person off-balance, that is, by the high amplitude transient motions that may occur when a vehicle traverses obstacles. Because of the likelihood of injury or even death in battle, soldiers are inclined to believe that the ability of the vehicle to perform its necessary functions during combat is more important than their own comfort. As a consequence, they tend to be satisfied with the ride characteristics of existing vehicles, and this tendency increases as they become acclimated to these characteristics.

The Armored Medical Research Laboratory<sup>123</sup> conducted an investigation of the relationship between physical effort and feelings of fatigue in tank crews. Of all the tank commander's tasks, the effort to hold and balance himself was found to require the greatest physical energy output.

<sup>122</sup>S. Sternick, D. Stimmel, and I. Sattinger. *Human Reaction to Military-Vehicle Ride*, Institute of Science and Technology for the US Army, University of Michigan, Ann Arbor, undated.

<sup>123</sup>*Appraisal of Kind and Degree of Physical Effort Required of Tank Crews in Relation to Fatigue*. Project No. 5-13, Armored Medical Research Laboratory, Research and Development Division, Office of the Surgeon General, Department of the Army, Fort Knox, Kentucky, March 1945.

This difficulty was due to the roughness of the tank's ride. The greatest physical energy expenditure for the gunner and driver was reported to be in maintaining a sitting position.

Sternick, et al., found that subjective evaluations of crew-vehicle capability appear to have an important bearing on performance, particularly with respect to maximum permissible speed at which off-road vehicles can traverse rough terrain. The results of their interviews with military personnel indicated that maximum speed is largely a function of the driver's evaluation of his own ability to withstand violent motions. Even at moderate speeds, the discomfort associated with vehicle motion can reduce crew morale or otherwise indirectly affect their capability. The results of the interviews also indicated fear of personal injury as an important factor in determining maximum speed.

Despite tankers' fears, they are probably as rugged as the vehicles they operate. For example, Horley,<sup>124</sup> in a study on the vibration tolerance of tank drivers, reported that the drivers can take more punishment than the tank suspension can.

#### Effects on Performance

Loeb<sup>125</sup> studied the effects of 98 dB of noise and two amplitude levels of 20 Hz vibrations. He found that, although noise did not affect his subjects' performance on a number of psychomotor and other tasks, increasing

<sup>124</sup>Personal Communication, in D. Cannon, E. Drucker, and T. Kessler, *Summary of Literature Review on Extended Operations*, HumRRO Consulting Report, Human Resources Research Organization, Alexandria, Virginia, December 1964.

<sup>125</sup>M. Loeb. *A Preliminary Investigation of the Effects of Whole-Body Vibration and Noise*, Report No. 145, US Army Medical Research Laboratory, Fort Knox, Kentucky, 1954.

levels of vibration progressively impaired visual acuity. The only other measure which was affected was a measure of manual steadiness. According to Loeb, "the nature of this effect is not a simple one since compensating mechanisms may be brought in at various intensities." Hornick<sup>126</sup> found that low frequency vibrations (similar to that encountered in moving vehicles) significantly impaired human performance involved in the control of a moving vehicle, i.e., compensatory tracking ability, choice reaction time, foot-pressure constancy, and peripheral vision, during and/or following vibration exposure.

Grether<sup>127</sup> investigated the combined effects of heat (120°F), noise (105 dB), and vibration (5.0 Hz, 0.30 Peak G) on tracking performance, choice reaction time, voice communications, mental arithmetic, and visual acuity. Various physiological measures (body temperature, heart rate, and weight loss) were taken. The combined effects of the three stressors used did not produce any greater effects than did the most severe single stressor. Of the two-way interactions, only heat stress was seen as producing further effects. Thus, in this study, noise and vibration were seen as producing the greatest performance decrement. Of the performance measures, particularly the tracking test, impairment was slightly less for the triple-stress condition than for vibration alone. A second study yielded essentially the same results.

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<sup>126</sup>R. Hornick. "Effects of Whole Body Vibration in Three Directions upon Human Performance," *Journal of Engineering Psychology*, July 1962, 1(3), 93-101.

<sup>127</sup>W. Grether. *Two Experiments on the Effects of Combined Heat, Noise, and Vibration Stress*, Aerospace Medical Research Lab, Wright-Patterson AFB, Ohio, 1972.

Mozell and White<sup>128</sup> studied the effects of double amplitude frequencies between 0 and 50 Hz with amplitudes of .05, 0.1, and .16 inches on subjects' performance in reading a mileage indicator, and performance in a tracking test. They found that frequencies above 8.0 Hz had adversely affected visual performance, with 40-50 Hz producing the greatest decrement in reading the mileage indicator. The vibration levels used in this experiment did not have any significant effects on tracking performance. Fraser, Hoover, and Ashe,<sup>129</sup> however, found a decrement in tracking performance related to the amplitude of vibration. The double amplitudes they studied were 1/16, 1/8, 3/8, and 1/4 inches, at frequencies of 2.0, 4.0, 7.0, and 12 Hz. They also found "a significant but inconsistent decrement ... under most circumstances when the display does not vibrate in conjunction with the subject."

Catterson, Hoover, and Ashe<sup>130</sup> also found a decrement, related more to amplitude than to frequency, in performance on a complex tracking task. They studied double amplitudes of .13 and .26 inches at frequencies ranging from 2.0 to 15 Hz. Although each of their subjects successfully completed the 20-minute exposure to each of the levels of vibration, all reported varying degrees of abdominal, back and chest pains at the higher vibration frequencies (60 to 15 Hz) with the .26 inch double amplitude.

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<sup>128</sup>M. Mozell and D. White. "Behavioral Effects of Whole Body Vibration," *Journal of Aviation Medicine*, 1958, 29, 716-724.

<sup>129</sup>T. Fraser, G. Hoover, and W. Ashe. "Tracking Performance During Low-Frequency Vibration," *Aerospace Medicine*, 1961, 32, 829-835.

<sup>130</sup>A. Catterson, G. Hoover, and W. Ashe. "Human Psychomotor Performance During Prolonged Vertical Vibration," *Aerospace Medicine*, 1962, 33.

Tracking proficiency declined early in the 20-minute period, but was no worse after 20 minutes than it had been after five minutes at each level of severity. A physician was in attendance during the vibration exposures, but none of the subjects suffered injury, nor did any of them voluntarily stop the vibration, although they were instructed to do so if the vibration became intolerable.

In his review of the subject, Linder<sup>131</sup> indicates that vibration has an adverse effect on aiming, auditory acuity, equilibrium, foot-pressure constancy, and reaction time. Collins,<sup>132</sup> in his literature review, cites studies which involved both horizontal and vertical motion components in a simple tracking task. In all the studies which used vertical vibration, it was found that the vertical component of tracking error showed significantly greater decrements than the horizontal component. Chaney and Parks,<sup>133</sup> who varied the two components separately in two different tasks, also found greater decrements in the vertical tracking task.

Studies by Hornick and LeFritz,<sup>134</sup> and Holland<sup>135</sup> approximated long-term vibration environments, and both found performance decrements over

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<sup>131</sup>G. Linder. "Mechanical Vibration Effects on Human Beings," *Aerospace Medicine*, 1962, 33, 939-950.

<sup>132</sup>A. Collins. "Decrement in Tracking and Visual Performance During Vibration," *Human Factors*, 1973, 15(4), 379-393.

<sup>133</sup>R. Chaney and D. Parks. *Tracking Performance During Whole-Body Vibration*, Technical Report No. D3-3512-6, The Boeing Company, Wichita, Kansas, 1964.

<sup>134</sup>R. Hornick and N. LeFritz. "Study and Review of Human Responses to Prolonged Random Vibration," *Human Factors*, 1966, 8, 481-492.

<sup>135</sup>C. Holland, Jr. *Performance and Physiological Effects of Long-Term Vibration*, Report No. AMRL-TR-66-145, Aerospace Medical Research Lab, Wright-Patterson AFB, Ohio, 1966.

time. However, Holland's study suggested that fatigue effects are no greater in vibration environments than in non-vibration environments.

Khalil and Ayoub<sup>136</sup> investigated the effects of work/rest schedules upon an individual's performance of a vertical compensatory tracking task performed in normal and vibration environments. Subjects performed this task using four work/rest schedules for a period of one hour. Some of their conclusions were: (1) vibration causes significant decrement in vertical tracking ability (absolute tracking error score increased by as much as 43 percent under vertical vibration); (2) complete recovery from vibration effects did not occur during the period (15 minutes) allowed for recovery; and (3) the work/rest schedules having the longer work/rest phases (30/30 minutes) showed less decrement in performance as measured by average error scores resulting from vibration than those having shorter work phases.

In a follow-on study by Dudek, Ayoub, and El Nawawi,<sup>137</sup> it was found that as the work/rest schedule increased from 30/30 to the 60/60 minute cycles, lower error scores were experienced in the vibrating environment. In a normal environment, increasing the work/rest times resulted in greater error scores. In general, the 30/30 minute work/rest schedule appeared to be best under all conditions in all the studies.

El-Nawawi<sup>138</sup> studied the effects of both normal and vibration environments upon different crew sizes. A simulated four-station work system was

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<sup>136</sup> T. Khalil and M. Ayoub. "Performance and Recovery Under Prolonged Vibration," submitted to *Human Factors*, 1970.

<sup>137</sup> R. Dudek, M. Ayoub, and M. El-Nawawi. "Optimal Work-Rest Schedules Under Prolonged Vibration," paper presented at the 4th International Congress on Ergonomics, Strasbourg, France, June 26-July 31, 1970.

<sup>138</sup> M. El-Nawawi. *Crew Performance in Extended Operations Under Vibrational Stress*, Doctoral Dissertation, Texas Tech University, Lubbock, 1971.

investigated with assignment of subjects to simulate eight-, six-, and five-man crew operation with two work cycle (60 and 30 minutes) used in the crew schedules. It was found that tracking error scores increased up to 21 percent under vertical vibration. Vibration effects on tracking accuracy remained the same the first and second two hours of the mission with wider dispersion in the latter two hours as well as indications of the effect of fatigue and/or boredom. In general, the 30-minute work cycle yielded lower tracking error scores than those obtained under the 60-minute work cycle schedules. The advantage of performance for the 30-minute work cycle schedules was greatly affected in the long duration (two hours) missions, especially under the vibration environment, which can be attributed to the smaller rest sessions provided in the work schedules.

#### Summary and Implications

It is clear from the literature that tankers fear injury while negotiating obstacles or rough terrain, especially at high speed. It seems likely that much of this fear, as well as actual injury, can be avoided by the judicious placement of crash pads and the employment of inertia-reel type safety harnesses such as are installed in many of the newer automobiles. Seats designed for greater comfort and safety should also be considered. Finally, in locations where crash pads cannot be used, sharp corners on projections could be eliminated. A veteran tank commander described his remedy for sharp projections to the senior author. He picked up a ballpeen hammer and said that he "whacked the hell out of anything that hung him" so that the corners or sharp edges would be rounded. A rather drastic approach to the problem, but, nevertheless,

it points to a need for more thorough planning when considering crew safety.

Vibration, especially the vertical component, appears to adversely affect tracking performance. Whether or not hit probabilities will be significantly degraded by vibration, and at what amplitudes and frequencies, could not be determined from existing data. Certainly, this area is in need of investigation.

While the data available indicate that vibration is a major concern to tank crewmen, vibration is not likely to be any greater during closed-hatch than open-hatch operations. Therefore, the only real concern peculiar to closed-hatch operations is the concern with the ability of crewmen to anticipate violent movements due to their reduced visual capabilities.

### Radiation

One problem which must be faced is the extent to which threat of exposure to radiation creates stressful conditions. Since performance under stress is frequently poorer than performance under other conditions, it becomes important to indicate ways in which these ill-effects may be avoided or overcome. The likelihood of tactical nuclear weapons being used in a mid- or high-intensity war is extremely high. It is important to be able to answer whether the threat of exposure to radiation will give rise to psychological stress. Some insights have come from a survey of current industrial practices with respect to the problem. The consensus of these practices is that stress and anxiety may be reduced by providing a realistic orientation to the situation and training personnel for emergencies.

A general finding reported by Smith and Cox<sup>139</sup> (generated from among support personnel who were not familiar with radiation safety procedures) was that they expressed their anxiety by blaming radiation for various unrelated symptoms which they had developed.

In the studies examined, there were no significant effects on performance due to ionizing radiation, except for the finding that if the dose was large enough to produce radiation sickness, that sickness would affect performance.

#### Effects of Radiation

Payne<sup>140</sup> reported that 200 roentgens was not enough to produce radiation sickness among a group of persons suffering from various forms of cancer. The radiation was given in a single dose or fractional doses over a five-hour period. Payne studied performance in a variety of psychomotor tasks, including rotary pursuit, two-hand coordination, and a test of complex coordination. A qualifying factor is that studies of the effects of radiation have been concerned only with accidents at nuclear reactor facilities, or with people suffering from neoplastic diseases. In this latter case, however, the dose of radiation is determined by the illness of the subject. In the studies by Payne, subjects were observed for a maximum of ten days. At the end of the ten-day period, there was an indication that performance had begun to fall among those subjects who had been exposed to greater amounts of radiation.

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<sup>139</sup>R. Smith, Jr., and J. Cox, Jr. *Methods of Induction of Psychological Stress Due to Radiation*, AFPTAC-TN-57-19, Personnel Laboratory, Air Force Personnel and Training Research Center, Air Research Development Command, Lackland AFB, Texas, February 1957.

<sup>140</sup>R. Payne. *Effects of Acute Radiation Exposure on Human Performance*, USAFSAM Rev. 3-63, 1963.

Cannon, Drucker, and Kessler,<sup>141</sup> quoting from an Air Force Manual,<sup>142</sup> stated that:

No permissible level for acute exposures has been established. Present knowledge (November 1962) indicates that 25 roentgens causes no observable reactions, 50 roentgens results in detectable changes in the blood, 100 roentgens produces nausea and vomiting, 300 to 550 roentgens gives the individual a 50-50 chance for survival without medical care, and 650 roentgens is lethal. Experimental animals will survive if the equivalent exposure is divided into two or more exposures separated by an interval of time; however, their life span may be shortened and tumors may develop.

Saenger's study<sup>143</sup> indicates that individuals who have had previous exposure will be less tolerant to subsequent exposure even after they have completely recovered. Individuals who were exposed previously may, upon being reexposed, become combat-ineffective immediately and become incapable of sustained or heavy work for weeks or months. Premonitory symptoms upon exposure to radiation are nausea, vomiting, anorexia, and lassitude which may last for hours. The intermediate effects usually last weeks. It was found that human beings recover slowly from the effects of radiation and are henceforth quite sensitive to radiation and often exhibit multi-system involvement.

Kennedy, Ball, and Hoot<sup>144</sup> estimated that the only immediate effects of an initial radiation dosage of up to 150 rems would be mild nausea within a few hours, followed by virtually complete recovery which would last for

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<sup>141</sup>D. Cannon, E. Drucker, and T. Kessler, *op. cit.*, 1964.

<sup>142</sup>*Nuclear Radiation Guide*. MRL-TDR-62-61, Aerospace Medical Division, 1962.

<sup>143</sup>E. Saenger. *Metabolic Changes in Humans Following Total Body Irradiation*, DASA 1422, University of Cincinnati College of Medicine, Cincinnati, 1963.

<sup>144</sup>T. Kennedy, J. Ball, and B. Hoot. *Expedient Field Fortifications for Use Against Nuclear Weapons* (U), AEWES Technical Report N-74-7, Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, September 1974.

approximately ten days. Therefore, men would be capable of fighting effectively for a considerable period of time following the decline of the hazard to relatively safe levels. The protection offered by a buttoned-up armored vehicle, coupled with its ability to move out of a radiation field, should offer occupants not in the immediate vicinity of the explosion a reasonable opportunity to avoid lethal or totally incapacitating dosages.

#### Efforts to Minimize Effects of Stress From Radiation

Smith and Cox<sup>145</sup> felt that the use of orientation training is the most feasible approach to avoiding the problem. It is frequently possible by training to change a fear of the unknown to a healthy respect for the known. It is important that orientation procedures be complete and effective, otherwise, the process may result in an underestimation of the seriousness of radiation, with attendant carelessness, and failure to adhere to safety standards.

For those persons who perform a standard job in an industrial radiation environment, realistic training and safety practices should be provided.

Smith and Cox concluded that:

Because of the demands of military operations, personnel may be exposed to higher levels of radiation than the nationally established rates. In view of the findings of the survey of nuclear industries, it is likely that a limited increase in the amount of radiation received may be made without increasing the stress problem to one of a major degree. The consensus is that by providing realistic orientation about the situation, and training people for emergencies, stress and anxiety may be reduced.

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<sup>145</sup>R. Smith, Jr., and J. Cox, Jr., *op. cit.*, 1957.

### Summary and Implications

One of the most effective ways of reducing the effects of stress from threat of exposure to radiation is to conduct individual and unit training in nuclear protective measures, tactics, and techniques. The armor crewman's chances for survival from a nuclear attack will be improved greatly in an armored vehicle. Army forces operating in a nuclear environment must expect exposure of personnel to radiation. Operations may dictate such exposure as a normal hazard of battle. Tanks provide excellent protection from the initial effects of blast, and both thermal and ionizing radiation. The tank's armor will provide excellent shielding against residual radiation. Additionally, the mobility of the tank will reduce the exposure time when leaving or crossing a contaminated area.

Following a nuclear attack, the greatest potential danger will be from fallout from the nuclear cloud and exposure to radiologically contaminated terrain. The tank can be fought buttoned-up, providing protection to the crew and contamination of the crew compartment will result only when crewmen open the hatches to perform the decontamination procedures.

Special training will be effective in reducing casualties from a nuclear attack. Training will be specially applicable to the psychological stress resulting from threat of exposure to radiation. This stress can best be overcome by an understanding of the principles involved and by well-developed procedures for dealing with the radiation hazard.

The primary effects of radiation, or the threat thereof, can probably be divided into two categories. First of all, there are the purely psychological effects that will occur from the realization of the

potential hazards. Secondly, there are the effects that may occur as the result of measures taken for protection against radiation effects. Individual Nuclear, Biological, and Chemical (NBC) protective gear does restrict both physical movement and perception. No research has been located which examines the effects of wearing NBC gear on performance in a buttoned-up tank. The psychological effects of exposure or threat of exposure to radiation hazards are virtually impossible to assess experimentally. However, research on the performance effects resulting from the use of NBC protective measures can and should be done.

#### Habitability (Personal Factors)

In one sense, all of the factors which are presumed to affect performance during buttoned-up operations can be considered to be habitability factors. Johnson<sup>146</sup> considered habitability to be comprised of the following nine principal elements:

1. Environment: The composition, temperature and movement of the respirable atmosphere, and the maintenance of adequate and comfortable acoustical and illumination levels.
2. Architecture: The geometric arrangement of quarters, work areas, companionways, stowage facilities, and equipment location and mounting provisions.
3. Mobility: The provisions made for lifting, moving equipment, and relieving feelings of restraint.
4. Dietary Sufficiency: The provision of adequate supplies of palatable food and liquid, including arrangements for stowage, preparation, serving, and eating.
5. Clothing and Personal Accoutrements: The provision of adequate and clean clothing, and personal articles.
6. Personal Hygiene: The availability of facilities for maintaining personal cleanliness and grooming.

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<sup>146</sup>C. Johnson. *Habitability of Manned Spacecraft*, paper presented at joint meeting of American Astronautical Society and Operational Research Society, Denver, Colorado, June 17-20, 1969.

7. Housekeeping: The provisions for cleaning, debris control, refuse disposal, laundering, and reprovisioning.

8. Communications: At least within the circumscribed physical environment.

9. Leisure Time Activities: The provision of equipment, a suitable psychological environment, and space to pursue chosen leisure time activities.

While Johnson's analysis is comprehensive and provides a good overview of the elements of habitability, he did not specifically mention either the need for privacy or the need for social interaction. Both of these may become critical where total habitable space is marginal and shared by other individuals. Parker and Every<sup>147</sup> did consider both of these factors. They quote Fraser,<sup>148</sup> who felt that privacy needs were important, and that some personal space must be provided. Sleep areas, for example, were cited as areas requiring some privacy. Parker and Every have also noted that mealtimes became a major source of both recreation and a time for social activity for aquanauts. Apparently, mealtimes were both pleasant and convenient times for social activity, and were utilized to fulfill this need.

Parker and Every also discuss Fraser's concept of the term *habitability*. Fraser states that habitability refers to the equilibrium state resulting from the interactions among the components of a man-machine/environment complex which permits men to maintain physiological

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<sup>147</sup>J. Parker, Jr., and M. Every. *Habitability Issues in Long-Duration Undersea and Space Missions*, Bio-Technology, Inc., prepared for the Engineering Psychology Programs, Office of Naval Research, Arlington, Virginia, July 1972.

<sup>148</sup>T. Fraser. *The Intangibles of Habitability During Long-Duration Space Missions*, NASA Report CR-1084, Lovelace Foundation, Albuquerque, New Mexico, June 1964.

homeostasis, adequate performance, and acceptable social relations. It can be seen that the term habitability, as defined in the literature, is quite broad. However, for purposes of this report, it will be restricted to factors concerned with the spatial, personal, and social environment of a habitat. This does not mean that the other factors are not considered important, as is obvious by the fact that separate sections of this review have been devoted to them. Rather, the term habitability seems to be a convenient label under which to discuss those factors which do not have a direct and obvious physiological effect on the human being, namely, those elements Johnson referred to under the realms of architecture, personal and social needs, and housekeeping.

#### Architectural Considerations

It is, in fact, impossible to completely separate architectural and housekeeping considerations. And, of course, the satisfaction of many personal needs is dependent upon the physical arrangements available. However, the basic architecture of a habitat is certainly the limiting factor in the arrangements that can be made for housekeeping and satisfying other needs.

As requirements for greater armor protection, larger weaponry, and more sophisticated acquisition systems, communications, and fire-control equipment have been placed on the designers of weapons systems, the internal or living space of tanks has decreased. The tanks of the future are expected to have even less space. Since no research on continuous operations in completely buttoned-up vehicles has been conducted, it is not possible to provide even a well-educated guess on how well crewmen

can adapt to long periods at close quarters in the limited space configuration of a tank. However, the best indications available point to a possible problem. An opinion poll taken during a habitability study by Celentano and Amorelli<sup>149</sup> showed that next to atmospheric conditions, living space requirements were considered to be the most important factor in habitability. There have been a number of studies on space requirements, but none of them directly applicable to the Army tank. Celentano and Amorelli concluded that an area of about 90 square feet and 700 cubic feet per occupant would be optimum for extended space voyages. However, tank crewmen will not occupy their vehicles for such extended periods. Hammes and Osborne<sup>150</sup> found that people could adjust adequately to living in as little as 10 square feet/person for up to two weeks in a fallout shelter. However, they had no functions to perform during their occupancy. Beevis and McCann<sup>151</sup> suggested a minimum of 90 cubic feet for a three-day stay in a vehicle. This study is probably the most relevant for consideration of tank habitability as it was concerned with occupancy of a vehicle. However, again, the occupants were not intended to perform any functions other than housekeeping and maintaining personal hygiene, as the vehicle was only intended to serve as a habitat when crewmen were stranded due to extreme arctic weather conditions.

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<sup>149</sup>J. Celentano and D. Amorelli. *Crew Status in Various Space Configurations and Volumes*, North American Aviation, Inc., Downey, California, June 1963.

<sup>150</sup>J. Hammes and R. Osborne. *Shelter Occupancy Studies at the University of Georgia, 1962-1963*, Civil Defense Research Psychological Laboratories, University of Georgia, Athens, December 1963.

<sup>151</sup>D. Beevis and C. McCann. *Human Engineering Aspects of a Small Self-Contained Mobile System*, DCIEM Technical Memo 875, Defence and Civil Institute of Environmental Medicine, Defence Research Board, July 1972.

The literature on confinement is, of course, relevant to this aspect of habitability. However, because confinement is known to be a potent factor in and of itself, separate sections of this report are devoted to confinement and its effects.

In summary, the limited space available, and its arrangement, in our current and anticipated armored vehicles, may be a significant source of psychological problems if personnel are forced to operate for extended periods in the buttoned-up mode. However, research into this area is surely needed, as little directly relevant information is available.

#### Personal and Social Requirements

Personal requirements may be divided into two categories. One category deals with hygienic requirements, the other with the less tangible needs for privacy and territory. Hygienic requirements have typically been given short shrift where space and/or weight restrictions were severe. For example, during the Mercury Space Program, there were not provisions for defecation and, fortunately, none were needed.<sup>152</sup> The crewmen were only in space for one day with the longest flight time being 22 hours. Crewmen in the Gemini program were furnished with rollon cuff/type urine collector and a plastic defecation bag. Dry and premoistened wipes were used. In the Apollo program there was no improvement in the personal hygiene facilities. In our armored vehicles no facilities are provided for handling urine or fecal matter within the vehicle.

Personal cleanliness has become an important need in our society. Hammes and Osborne<sup>153</sup> have suggested that one quart of water per day per

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<sup>152</sup>J. Parker, Jr., and M. Every, *op. cit.*, July 1972.

<sup>153</sup>J. Hammes and R. Osborne, *op. cit.*, December 1963.

inhabitant of a fallout shelter for use in "sponge baths" and brushing teeth would provide an enormous psychological lift to occupation. Johnson<sup>154</sup> agrees, stating that facilities need not be exotic, and that an old-fashioned washcloth is generally satisfactory and can be used over and over. No provision for washing the body is provided in our current armored vehicles.

Requirements for privacy have not been considered in the design of our armored vehicles. No space for stowing personal articles is provided within the vehicle. No provision for privacy for defecating or urinating has been made. No "territorial rights" for any purpose have been set forth in official doctrine. This is undoubtedly because our current tanks were not designed for occupancy for more than a few hours at a time. However, if we expect crews to remain buttoned up for extended periods, these factors must be considered.

Social, or person-to-person interaction factors, might be expected to take on increased importance if tank crews must remain in their vehicles for extended periods. However, Eberhard<sup>155</sup> reviewed a number of studies dealing with activities during long periods of confinement, and found solitary activities to generally predominate. While talking was engaged in, reading, watching movies and television were also very popular. Eberhard also found that men in confinement took almost twice as long to eat as unconfined men. It may be that much of the social interchange took place at the table, as was also indicated by Parker and Every.<sup>156</sup>

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<sup>154</sup>C. Johnson, *op. cit.*, 1969.

<sup>155</sup>J. Eberhard. *MOL Minimum Crew Volume Requirements*, unpublished report prepared for Douglas Aircraft Corporation, March 1966.

<sup>156</sup>M. Parker, Jr., and M. Every, *op. cit.*, December 1963.

Helmreich,<sup>157</sup> in his studies of men in undersea habitats, also found that solitary activities were popular. Playing cards was a frequently observed leisure time activity, but cardplaying is often more of an intellectual and competitive activity than a social activity.

It may be that persons confined in small spaces and forced to work with the same small group of individuals day after day have little desire for purely social interchange with the same individuals, and prefer solitary activities. Whether this will be true of tank crewmen on long missions can only be determined through future research.

#### Housekeeping Requirements

The Defence Research Establishment undertook the development of a small mobile arctic shelter. The Defence and Civil Institute of Environmental Medicine was asked to provide assistance in the design and development of the shelter to ensure adherence to human engineering criteria. This effort was reported by Beevis and McCann.<sup>158</sup> The state that:

There is evidence that the physical and sensory restrictions during confinement for several days can have adverse psychological effects for personnel. Most of the work involved in trying to determine the minimum acceptable shelter volume for man for such conditions has been those studies which were concerned with space capsules and submarines, in which the crew cannot leave under any circumstances.

Beevis and McCann recommended that a minimum of some 90 cubic feet be provided per man for up to three days confinement, although this cannot be considered an absolute limit. A "Snotruk," which was a tracked vehicle,

<sup>157</sup>P. Helmreich. *Evaluation of Environments: Behavioral Observations in an Undersea Habitat*, Social Psychology Laboratory, Department of Psychology, University of Texas, Austin, August 1971.

<sup>158</sup>D. Beevis and C. McCann, *op. cit.*, July 1972.

was modified to support the activities of two men on patrol for up to five days in the arctic region. The roof height of 50 inches was a compromise between the requirements for changing clothing and getting in-to and out of a sleeping bag, and the head clearance required for sitting when using the water closet and moving about inside the cab. Extra insulation was required on the interior walls as the interior wall temperature was calculated to drop as low as 5°F in some conditions.

These workers recognized the need for some privacy even with this minimum space. For example, they provided for a curtain to be hung in front of the water closet.

Garbage accumulation was seen as a problem, and these investigators suggested that plastic bags with drawstrings be provided to bag each day's accumulation. Storage space for these bags must also be provided. Waste disposal was to be handled by a recirculating-type toilet, with a built-in holding tank which could be used for periods up to several weeks. Heating requirements were calculated as 4000 British Thermal Units (BTUs) per hour to maintain a shelter temperature of 35°F during the time the engine was not running. The figure of 4000 BTUs was based on an assumed exterior temperature of -35°F, and a wind speed of 40 Miles Per Hour (MPH).

An air flow of five CFM per man was considered as the minimum at all times, with up to 35 CFM of air flow at a rate of 100 feet per minute, which is the upper comfort level for air movement. These authors concluded that the efficiency of the heating and ventilation systems must be assessed under realistic conditions as no reliable prediction can be made on the basis of prior calculations, particularly in the case of ventilation.

In addition, these writers gave detailed attention to requirements for such things as utensils and other kitchen accoutrements. However, such luxuries are out of the question for armored vehicles, at least in the foreseeable future.

### Summary and Implications

Recent increased interest in habitability of confining environments stems largely from an increased interest in maintaining man for long periods in space or undersea habitats. The term habitability has taken on a broad meaning in the literature, but for purposes of this report, it is limited to those spatial, personal, social, and housekeeping factors that do not have a direct and primarily psychological effects on man.

In general, it has been found that man can survive in a very limited amount of space. However, he needs at least some privacy, and feels strongly about personal cleanliness and other hygienic factors. He has some social needs during confinement, but tends to satisfy these at meal-times, generally preferring solitary activities for leisure.

The habitability of tanks for long periods, especially buttoned up, does not seem to have even been given consideration by the US. Space for stowage of personal items, means for eliminating waste, or storage and means of dispensing food and liquid is almost totally lacking. In brief, how habitable a tank might be for periods of more than a day has never been examined, but indications are that problems might become severe.

## Human Engineering

### Crew Compartment

The Army's requirement that future tanks be able to penetrate nuclear battlefields and survive has changed tank design. The tank must be able to operate effectively with its hatches closed for varying periods of time. The crew must be able to work during such periods in a closed compartment isolated from the outside environment. Many of the factors which contribute to less than optimum performance during buttoned-up operations can be eliminated or the effect lessened by the application of sound human engineering principles. A survey conducted by the Army Medical Research Laboratory<sup>159</sup> collected information on the problems encountered by tank crews which might be alleviated by human engineering research. A total of 894 individuals attending the Armor School at Fort Knox, Kentucky, were questioned. Using the critical incident technique, of 894 incidents reported, 623 (69.7 percent) were concerned with problems of interest for human engineering for each job were: (1) tank commander, problems of communication; (2) gunner, problems of space allotment; (3) loader, problems dealing with his position; and (4) driver, problems arising from interference with his Field of Vision (FOV). However, these results may actually underestimate the number of problems which exist. The research staff observed that "to ask a man who has used equipment for a long time to state its shortcomings may be fruitless, since frequently he has adjusted to its shortcomings and no longer recognizes them as such. Thus, some important problems might well go unemphasized in this type of critical incidence survey."

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<sup>159</sup> *A Survey of Tank Crew Problems*. Report No. 39, Psychology Department, US Army Medical Research Laboratory, Fort Knox, Kentucky, August 1952.

Horley, et al.,<sup>160</sup> recommended that specific studies in the buttoned-up mode should address themselves, for example, to the detection of aircraft, typical ambush-site situations, the potential degradation in overall tactical mobility, and possible loss of vehicle orientation due to limitations on visibility. This disorientation was also observed in a study conducted by HQ MASSTER. Interviews with tank commanders indicated a loss of orientation, especially when slewing at maximum rates.

Schroetter<sup>161</sup> pointed out that the correct seating posture increases the accuracy of work and reduces fatigue. Any rigid and strained posture will cause poor performance. In designing a tank driver's seat, not only the width and depth of the seat must be considered, but also the adjustability of the seat and its position in relation to the operating unit. This seat should, moreover, provide protection against mechanical vibrations. This protection can be accomplished by suitable tuning of the seat suspension and damping. Adaptation of the static depression of seat springs to accommodate different weights of drivers will also be necessary. Very little space will be required to accommodate the full range of human size variability likely to be encountered.

Distance to the driving pedals should remain invariant, regardless of seat adjustment. Also, the direction of application of force on the pedals should not differ too greatly as a result of the seat variability.

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<sup>160</sup>G. Horley, A. Eckles, and R. Dax. *Target Detection: A Comparison of Several Vision Systems Mounted in Stationary and Moving Tanks* (U) Technical Memorandum 7-67, US Army Human Engineering Laboratories, Aberdeen Proving Ground, Maryland, March 1967.

<sup>161</sup>H. Schroetter. "Ergonomics and Its Importance to the Development of Fighting Vehicles," *Truppenpraxis*, 1972, 1, 28-32 (Library Translation for Royal Aircraft Establishment, B. Crossland and L. Croton, translation editors).

The optimal direction for application of force on the pedals is 70 degrees.<sup>162</sup> The pedals must be designed to ensure a reliable control with the foot; they should not be too close together, and should not be too high. Both of these latter factors can lead to conditions under which errors occur.

A human factors evaluation of the M60A1 tank by Dickinson and Brown<sup>163</sup> found that the addition of a fore and aft adjustment on the commander's seat would allow sufficient leg space between his seat and the gunner's backrest. With a 95 percentile commander seated, lack of an adjustment capability will interfere with the tank commander's leg movement. They also found that the escape hatch will accommodate a 95 percentile man, without arctic clothing. Arctic clothing will increase torso dimensions to approximately four inches wider than the hatch opening. It is assumed that some problems of the same nature would occur with the wearing of CBR protective clothing.

The human eye requires approximately two seconds to adapt from far to near vision. This accommodation time may present a source of danger and, to counter it, some vehicles have been designed with the most important driving instruments and warning lights located on the same plane on a steering column bracket. This arrangement is designed in such a fashion that when the driver's seat is raised or lowered, the instrument panel will move to remain in the same plane.

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<sup>162</sup>*Ibid.*

<sup>163</sup>N. Dickinson and G. Brown. *A Human Factors Evaluation of the Main Battle Tank, 105mm Gun, M60E1*, Technical Memorandum 14-62, US Army Human Engineering Laboratories, Aberdeen Proving Ground, Maryland, June 1962.

### Target Acquisition Devices

Modern tank weapons have become so accurate and lethal that who sees who first often determines who survives on the battlefield. When performing surveillance with binoculars from an open hatch, no one tank has any particular advantage. But when conditions require that all tanks button p, differences in optical or remote viewing systems may well determine the outcome of the battle.

Horley, et al.,<sup>164</sup> conducted two target detection studies in which they compared target detection performance with several viewing systems against target detection performance from the open hatch. Observers were placed in stationary tanks and were asked to detect defending (stationary) and attacking (moving) targets. Differences in percentage detections between the closed-hatch (Greenhouse) and open hatch modes were approximately 15-18 percent, with the closed-hatch mode faring more poorly. Differences between the gunner's periscope and the open-hatch mode were approximately 10-12 percent, with the gunner's periscope being the poorer system. A TV detection system performed most poorly. The Greenhouse was a wooden mockup with five unity-power vision blocks placed side-by-side to form an uninterrupted area of vision to the front and sides.

In their second study, Horley, et al., compared the performance of five viewing systems from both a stationary and a moving tank. They found that defending (stationary) targets, before they began firing, were harder to detect than attacking (moving) targets for all systems, except for the gunner's periscope. They evaluated the following systems: (1) gunner's

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<sup>164</sup>G. Horley, A. Eckles, and R. Dax, *op. cit.*, March 1967.

periscope, (2) open-hatch with binoculars, (3) closed-hatch (Greenhouse) with binoculars, (4) telescope, and (5) Image-Orthicon TV. The periscope was superior to other systems in detecting both stationary and moving targets in most cases.

The condition which produced the poorest detection performance was when both the observer and the target tanks were moving. This could be due to the high probability of interruption of the line-of-sight by terrain features when both were moving. They concluded that TV for surveillance on the move should be considered. On rough terrain where the tank is moving, gunners may have difficulty maintaining eye alignment with optical system eyepieces. A TV presentation which can be viewed from a slight distance might offer an advantage.

Results of these two studies further indicated that wider FOVs are important for quick response to open targets that are moving. Conversely, these results show that magnification is important for detecting concealed targets and that stabilization is required for surveillance on the move. An ideal surveillance system would be a combination system integrating two units -- one low power unit for wider FOV, and a second incorporating high magnification with stabilization -- arranged so that the tank commander could shift from one to the other without losing his orientation to the terrain.

#### Stabilized Gunnery

A study by Linley and Werner<sup>165</sup> investigated stabilized gunnery on the move, using two weapon systems, a 25mm and a 20mm rapid fire cannon.

<sup>165</sup>L. Linley and A. Werner. *Report on General Performance of Tested XM701 Turret Weapon Stabilization Systems*, Technical Report No. 11584, Pacific Car and Foundry Company, Renton, Washington, March 1972.

They concluded that an average gunner could maintain his aim at a four-mil diameter target at least 43 percent of the time at cross-country speeds up to and including 20 MPH. An unmanned system could maintain its aim in a four-mil diameter zone 100 percent of the time at cross-country speeds up to and including 20 MPH. Most of the observed errors were due to gunner attempts to correct for translation and illusionary errors. They reported that the average Army gunner has a 60 percent minimum and a 93 percent maximum probability of hitting a target eight mils in diameter at 20 MPH. The addition of a stabilization system results in a significant improvement in hit capability. To be able to fully utilize the stabilization system, the gunner must be given comprehensive training, including experience in firing from a moving vehicle. A gunner's sight specifically designed for use with the stabilization system is needed to eliminate target image vibration and blackout, reduce gunner fatigue, etc. Restraint and seating arrangements are generally fatiguing to the gunner in a stabilized moving vehicle. Gunners become fatigued by the restraint and seating arrangements in a stabilized moving vehicle due to the physical effort required to maintain their body and head positions while firing on the move. High speed turrets in the stabilized mode will require close attention to safety procedures because of increased centrifugal force and continuous motion.

#### Summary and Implications

No studies were uncovered which attempted to specify or define the human factors requirements necessary for the design of future tanks to enhance operations in a closed-hatch mode for extended periods of time.

Separate studies dealing with CBR equipment compatibility, clothing, and surveillance were found, but reports of systematic endeavors concerning human factors considerations in buttoned-up operations were lacking.

When a tank crew closes the hatches, visual capabilities become degraded. The current effectiveness of our tanks depends upon adequate surveillance and target detection capabilities. Therefore, it is desirable for the crew to maintain the same performance levels with the hatches closed or open. Through proper consideration for the human factors aspects, coupled with technological advances, this may be possible.

In redesigning tanks and associated individual equipment to maximize performance during buttoned-up operations, it is important to define the conditions under which these operations are likely to occur. For example, the likelihood of actually fighting in a CBR environment must be considered. The more likely this or any other given set of conditions are to be encountered, the greater is the need for our equipment to be designed to operate in those conditions.

The crew should be considered a part of the system and the design should ensure the smooth incorporation of their abilities into the overall scheme of system operation. Shoe-horning the armor crewman in after all other things have been set in concrete does not result in an optimally effective system.

#### WORK/REST CYCLES

Advances in military technology have given man the capability to engage in long-duration missions. The rapid development in recent years of night vision equipment has enabled continuous battlefield operations, provided combat and combat-support personnel are able to meet the increased

demands. In order to attain optimum performance, the selection of optimum work/rest schedules for personnel engaged in long-duration missions is obviously desirable. Ideally, these schedules would tend to maximize duty time while minimizing decrements in performance. In addition, such schedules should allow organization of personnel into shifts (or watches) and should avoid harmful physiological or psychological reactions.

#### Atypical Work/Rest Cycles

Alluisi, et al.,<sup>166</sup> has pointed out that in the military individuals will often be called upon to perform under rather rigorous atypical work/rest conditions. These may be situations which will demand 24 hour-day operations on a high alert basis. These situations will occur in combat and will serve to dramatically change working conditions. Sustained or continuous operations will vary the normal routine for armor crews. In these situations, armor crews may have to perform with less rest and sleep than is usual. It is also likely that the crews may not have had the chance to become previously adjusted to these work/rest cycles or have had previous training in them.

In an atypical non-24 hour cyclical schedule of activity, individual physiological rhythms will show some but not complete adaptation. Individuals differ widely in their ability and the speed with which maximum adaptation occurs. Alluisi, et al., indicated that within broad limits performance did not vary significantly as a function of the work/rest cycle, provided the work/rest and sleep/wakefulness ratios were held constant and

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<sup>166</sup>E. Alluisi, W. Chiles, and R. Smith. *Human Performance in Military Systems: Some Situational Factors Influencing Individual Performance*, Interim Technical Report 64-1, Performance Research Lab, Department of Psychology, University of Louisville, Louisville, Kentucky, August 1964.

the period of observation did not exceed one week. Little data are available to allow valid generalization to longer periods of time. Man is apparently capable of maintaining high-level performance on various tasks while living according to rather rigorous atypical work/rest scheduling, at least for short periods.

#### OPTIMUM WORK/REST CYCLES

Alluisi, Chiles, and Hall<sup>167</sup> found that subjects who worked 12 hours a day on a 4/4 work-rest schedule were able to maintain their performance at a higher level than subjects who worked 16 hours a day on a 4/2 schedule. Generally, the performance of subjects on tasks which required sustained attention declined while maintaining a 4/2 schedule, even though the periods of sustained attention were relatively short. They concluded that where given levels of performance are a critical requirement during emergency periods, the 4/2 schedule should be used only with extreme caution, because this schedule typically places a performance stress on the individual from the start.

Adams and Chiles<sup>168</sup> measured the performance of 60 subjects over a period of 96 hours as a function of four different duty/rest cycles (2/2, 4/6, 6/6, and 8/8). It was evident from the results that subjects could work at their assigned tasks and maintain their efficiency working 12 hours a day for periods up to as long as 96 hours. In particular, the 4/2 schedule can be followed and acceptable performance levels of selected

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<sup>167</sup> E. Alluisi, W. Chiles, and T. Hall. Combined Effects of Sleep Loss and Demanding Work/Rest Schedules of Crew Performance, Report No. AMRL-TDR-64-63, Aerospace Medical Research Labs, Aerospace Medical Division, Air Force Systems Command, Wright-Patterson AFB, Ohio, June 1964.

<sup>168</sup> O. Adams and W. Chiles. Human Performance as A Function of the Work/Rest Cycle, WADD Technical Report No. 60-248, Wright-Patterson AFB, Ohio, 1960.

and motivated subjects will be maintained for at least two weeks to a month. Performance was generally better on the 4/4 schedule and could be maintained for 30 days. The authors concluded that the 4/4 schedule could probably be followed for 60 to 90 days during actual missions without decrements in performance. Subjects on duty performed six tasks (arithmetic computations, auditory vigilance, warning light monitoring, target identification, probability monitoring,<sup>169</sup> and code lock-solving<sup>170</sup>). Alluisi and Chiles<sup>171</sup> concluded that a person following a 4/2 schedule uses up his performance reserve and so is less likely and able to meet the demands of emergency situations.

In a series of four studies, Morgan, et al.,<sup>172</sup> investigated the effect of continuous work on human performance. The results of these studies were quite consistent. Performance efficiency in all of these studies began to deteriorate after about 14 to 18 hours of continuous work, reaching its lowest point after 22 to 24 hours. Performance then improved

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<sup>169</sup>Probability monitoring was a watchkeeping task that required the subject to integrate a random process (meter fluctuations) over time in order to detect a relatively infrequent shift in the mean value of the process.

<sup>170</sup>Code lock-solving was a group-performance crew task that required the subjects to discover the correct sequence in which one of five buttons (one operated by each of the five subjects in a given crew) has to be pushed to illuminate a green light. Subjects were required to do this as quickly as possible without neglecting their other duties.

<sup>171</sup>E. Alluisi and W. Chiles. "Sustained Performance, Rest Scheduling, and Diurnal Rhythms in Man," *Acta Psychologica*, 1967, 27, 436-442.

<sup>172</sup>B. Morgan, Jr., G. Coates, B. Brown, and E. Alluisi. *Effects of Continuous Work and Sleep Loss on the Recovery of Sustained Performance*, Technical Report No. 14-73, US Army Human Engineering Laboratories, Aberdeen Proving Ground, Maryland, 1973.

to about the thirtieth or thirty-second hour, then decreased slightly thereafter. Both the pattern and degree of recovery were related to the length of the continuous work period, as well as to the amount of rest and recovery provided. Recovery of performance was incomplete in all cases, but four hours of rest following 36 hours of continuous work produced a significant degree of recovery.

#### Effects on Performance

Brown, et al.,<sup>173</sup> indicated that circadian rhythms are a primary determiner of man's ability to work continuously for extended periods of time and to recover from the effects of both continuous work and sleep loss. Morgan, et al.,<sup>174</sup> found that after 36 hours of continuous work and sleep loss, recovery was less complete for crews whose work cycle began during the low portion of their circadian rhythm (i.e., work cycle starting at 0400 hours in the morning).

Adams and Chiles,<sup>175</sup> in a review of the literature of work/rest cycles, found that the degree of performance decrement during extended hours of wakefulness is a function of the length of the performance testing period and the type of task involved. In general, if the tasks are simple and if the performance period is of a short duration, there are no observable pronounced decrements. These authors suggest that four hours is the

<sup>173</sup>B. Brown, B. Morgan, Jr., J. Repko, and G. Coates. *Interaction of the Circadian Rhythm With the Effects of 36 Hours of Continuous Work and Sleep Loss*, Organizations and Systems Research Laboratory, (Technical Research Note, in preparation).

<sup>174</sup>B. Morgan, Jr., B. Brown, G. Coates, and J. Repko. *Effects of the Circadian Rhythm on Sustained Performance During 36 Hours of Continuous Work and Sleep Loss*, Organizations and Systems Research Laboratory (Technical Research Note, in preparation).

<sup>175</sup>O. Adams and W. Chiles. "Human Performance and the Work/Rest Schedule," *Human Factors in Technology*, Bennett, Deagen, and Spiegel, 1963.

maximum duty period when the following conditions are present: a passive task combined with one or more active tasks, low work loads, and continuously maintained high levels of performance. When only a passive isolated task occurs, a two-hour duration is probably the maximum advisable. If there is active participation with the major tasks, considerable variety in the tasks, and if the signals to which the operator must respond are easily detectable, the duty period can be extended routinely to eight or ten hours.

Some of the major conclusions that Chiles and Adams<sup>176</sup> drew were:

1. Performance of critical tasks by individuals who must remain awake for 24 hours are not feasible as a routine procedure.
2. Six hours of sleep are adequate for most individuals.
3. Sleep periods should not be less than two hours in duration.
4. Continuous performance of monotonous tasks by themselves should not exceed two hours.
5. Total work/rest cycle durations should be four, six, eight, or 12 hours in order to permit regular day-to-day schedules.
6. Seven or eight days of pretesting should be adequate to select personnel adaptable to schedule changes.
7. A five-day preadaptation period should be used to overcome initial sleep losses.

Ray, Martin, and Alluisi<sup>177</sup> have reviewed only those studies in which performance was extended for 24 hours or longer and in which the results were pertinent to optimizing performance through the scheduling of work/

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<sup>176</sup>W. Chiles and O. Adams. *Human Performance and the Work-Rest Schedule*, USAF ASD Technical Note No. 67-170, Aeronautical Systems Division, Wright-Patterson AFB, Ohio, 1967.

<sup>177</sup>J. Ray, O. Martin, and E. Alluisi. *Human Performance as a Function of the Work-Rest Cycle: A Review of Selected Studies*, Publication No. 882, National Academy of Science, National Research Council, Washington, D.C., 1961.

rest periods. The studies reviewed generally indicated that man's performance and his physiological processes exhibit variations that are due to man's adaptation to a 24-hour day. These physiological rhythms show some but not complete adaptation to a non-24 hour cycle. These authors concluded that performance does not appear to vary significantly as a function of the work/rest cycle, provided that the work/rest and sleep ratios are held constant and the period of observation does not exceed one week. An exception to this statement is the decrement observed in the performance of certain vigilance tasks. These passive tasks seem to be more sensitive to the effects of atypical work/rest schedules than more active tasks.

Ramsey, Halcomb, and Mortagy<sup>178</sup> have investigated the effects of self-determined work/rest schedules on performance. They found that subjects who chose "long" sessions to optimize their performance scored significantly poorer than those who chose "shorter" sessions.

Alluisi, Chiles, and Hall<sup>179</sup> found that subjects on a 4/2 schedule performed poorer as a result of going without sleep for 44 hours. This difference was significant for those tasks requiring close concentration (arithmetic and probability monitoring) even though concentration was sustained for only seconds. Subjects who followed a 4/4 schedule recovered their pre-sleep performance levels within 12 hours following the period of sleep loss. Subjects on the 4/2 schedule took 14 hours to recover.

<sup>178</sup> J. Ramsey, C. Halcomb, and A. Mortagy. "Self Determined Work/Rest Cycles in the Heat," in D. Hodge (ed.), *Military Requirements for Research on Continuous Operations, Proceedings of a Conference Held at Texas Tech. University, Lubbock, Texas, 28-29 September 1971*, Technical Memorandum 12-72, US Army Human Engineering Laboratories, Aberdeen Proving Ground, Maryland, April 1972.

<sup>179</sup> E. Alluisi, W. Chiles, and T. Hall, *op. cit.*, June 1964.

Adams, et al.,<sup>180</sup> reported that several studies by Wilkinson and Stretton<sup>181</sup> have demonstrated that performance is less efficient within the first 10 minutes of wakening. Any decrement present upon wakening tends to disappear within 10 minutes of wakening.

Lauer and Suhr<sup>182</sup> have found that individuals who drove six hours with a rest period every 30 minutes received consistently higher driving scores than drivers who drove six hours without rest. Further, drivers who had rested were also able to respond quicker to an attention light.

Langdon and Hartman<sup>183</sup> have studied the effects of sleep interruption on performance. Performance was measured before sleep and within two minutes of being aroused. Five airmen were awakened three times during their normal sleep period. This study was conducted over a five-day period and subjects were tested on the Complex Behavior Simulator. It was found that performance was 25 percent worse after being awakened than it was at pre-sleep levels. However, performance did improve during the ten-minute test period.

Hartman and Cantrell<sup>184</sup> confined subjects for 12 days and followed a 4/2, 4/4, or 16/6 schedule. On days 8, 9, and 10, subjects were deprived

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<sup>180</sup> A. Adams, H. Huddleston, B. Robson, and R. Wilson. *Some Effects of Sleep Loss on a Simulated Flying Task*, Technical Report 72168, Royal Aircraft Establishment, October 1971.

<sup>181</sup> R. Wilkinson and M. Stretton. "Performance After Awakening at Different Times of Night," *Psychonomic Science*, 1971, 23, Part 4, 283-285.

<sup>182</sup> A. Lauer and V. Suhr. "The Effect of a Rest Pause on Driving Efficiency," *Perceptual and Motor Skills*, 1959, 9, 363-371.

<sup>183</sup> D. Langdon and B. Hartman. *Performance Upon Sudden Awakening*, USAFSAM Report 62-17, School of Aerospace Medicine, Brooks AFB, Texas, 1961.

<sup>184</sup> B. Hartman and G. Cantrell. *MOL: Crew Performance on Demanding Work/Rest Schedules Compounded by Sleep Deprivation*, Technical Report 67-99, School of Aviation Medicine, Brooks AFB, Texas, November 1967.

of sleep while performing psychomotor tasks continuously during a 68-72 hour period. The tasks performed were: vigilance, arithmetic computation, tracking, short-term memory, complex coordination, and multiple reaction time. There were no differences in performance as a function of work/rest cycle, as long as schedules were the only experimental manipulation. Progressive decrements were observed under all schedules when compared with sleep deprivation. In general, the 16/8 schedule resulted in better performance and more rapid and substantial recovery from the effects of sleep deprivation.

Colquhoun, Blake, and Edwards<sup>185</sup> investigated the efficiency with which mental tasks were performed by individuals standing watches of eight hours duration over a period of 12 consecutive days. Three work watches were used: (1) 0800-1600 hours; (2) 2200-0600 hours; and (3) 0400-1200 hours. They found that performance efficiency varied considerably during all three watches. The changes appeared to be related to concurrent fluctuations in body temperature arising from diurnal physiological rhythms. The best performance was in the first four hours of the day watch. It took six nights on the night watch for the normal rhythm of body temperature to adapt to the new sleep-waking cycle. During this six day period, performance fell each night with the drop in body temperature. In the second six nights, the fall in body temperature was considerably reduced by partial physiological adaptation and the performance decrement was effectively abolished.

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<sup>185</sup>W. Colquhoun, M. Blake, and R. Edwards. *Experiments on Eight-Hour Standing Watches in a Three-Watch System*, Report No. RNP-69-1123, OES-478, Royal Naval Personnel Research Committee, London, England, July 1968.

Morgan and Alluisi<sup>186</sup> presented a paper in 1971 to the Conference on Continuous Operations in which they described their work on work/rest cycles. They felt that underlying man's activities there is a biological or psychophysiological circadian rhythm which is conditioned at least to some extent by those activities. They found that performance may show the same sort of rhythm, with a lag of about two hours or so behind the circadian rhythm, depending on other factors. As work/rest schedules are varied from the norm, the points of peak activation (and performance) seemed to slip about two hours every five days or so. *The change in this cycling suggests that biological or physiological adaptation to atypical work/rest schedules will take at least 20 days, and perhaps as long as 25 to 30 days on the average.* One of the simplest means to adapt a person to a new schedule is to have the person stay awake sufficiently long to assure that the normal diurnal cycle is broken, and that a new cycle begins when sleep is permitted.

In normal situations, if motivated, man is able to exert extra effort to overcome the effects of circadian rhythm on performance. While performance may or may not follow the diurnal cycle during normal work periods, it is likely to do so during periods of continuous operations. During extended operations, man's performance not only interacts with the underlying circadian rhythm, but also with the total demands of his work activity and with the prior expenditure of his performance reserves.

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<sup>186</sup>B. Morgan and E. Alluisi. "Applicability of Research on Sustained Performance, Endurance, and Work-Rest Scheduling to the Development of Concepts and Doctrine of Continuous Operations," in D. Hodge (ed.), *Military Requirements for Research on Continuous Operations, Proceedings of a Conference Held at Texas Tech University, Lubbock, Texas, 28-29 September 1971*, Technical Memorandum 12-72, US Army Human Engineering Laboratories, Aberdeen Proving Ground, Maryland, April 1972.

### Summary and Implications

Apparently, man is capable of maintaining high-level performance on various tasks while living according to rather rigorous atypical work/rest scheduling -- at least for short periods of time. There is an abundance of recommendations on management of work/rest cycles; whether or not they can be followed during armor ground combat has yet to be evaluated. Vehicle design may have to be modified if crews are to operate continuously for extended periods of time with provisions to allow rest during periods of reduced activity. Each crew member must be able to rotate with every other crew member, making job interchangeability mandatory. Crew stations may have to be redesigned so multiple tasks can be performed by an abbreviated crew. Rest stations or areas will have to be provided for.

Previous research in this area has dealt primarily with the type of tasks that would be performed during space missions. Research dealing with tasks typical of armor ground combat has not been initiated. The level of performance to be expected immediately after being suddenly awakened is largely unknown. The use of catnaps is an essential area for future research in work/rest cycling.

Within broad limits, it appears that performance does not seem to vary significantly as a function of the work/rest cycle provided the work and rest ratios are held constant and the period of observation does not exceed one week.

Within armor doctrine very little is said about providing relief among crew members during periods where crew member activities are disproportionate. In field studies, the tendency has been for the tank commander

to spend more time on duty than any other member of the crew. Evidently, they feel they are responsible for their crew's performance or are afraid to delegate their authority. It may be necessary in field testing to allocate mandatory work cycles in order to force job interchangeability training.

### Enhancement of Performance by Drugs

One of the major problems in conducting military operations over extended periods of time is to maintain sufficient resources so that units in actual combat can be relieved before they begin to suffer from the effects of fatigue, sleep loss, or other factors. In a mid-intensity or high-intensity war, it may not be possible to relieve units on a regular basis. Thus, many units may have to perform close to their upper limits, at least for short periods of time. Under these circumstances, it may be possible to alleviate the effects of sleep loss and fatigue by the diligent use of drugs. It is possible that the use of drugs can reduce the amount of time required by an individual to recuperate from total exhaustion. Also, it may be that drugs can substitute for sleep. In particular, the use of drugs may allow an individual to: (a) expend greater amounts of energy over varying periods of time, (b) operate at a more efficient level, (c) delay the effects of fatigue, and (d) cause individuals to be more alert during the performance of monotonous or solitary tasks.

During WWII it was observed that the Germans used amphetamines to improve performance in their troops. The general effect of drugs such as some amphetamines, benzedrine, methedrine, and caffeine have been found

to enhance the performance of fatigued individuals, but their effectiveness seems to lessen with continued use. If exhaustion is already present, the administration of these drugs can be likened to flogging a dead horse.

Continuous or sustained operations, whether buttoned up or not, will require greater physical and mental effort than has been encountered in the past. If individuals or units must perform at high levels without relief, the use of drugs in an emergency situation could make the difference between the success or failure of a vital mission.

With the increased emphasis on the feasibility of conducting military operations for extended periods of time, the results of drug research to enhance performance takes on a renewed importance.

#### Military Field Studies

A number of studies have been undertaken to determine the effectiveness of amphetamine-type drugs in enhancing performance in military tasks. Platnikoff, et al.,<sup>187</sup> report that the most extensive series of studies using military subjects was conducted by Seashore and Ivy.<sup>188</sup> They attempted to simulate as closely as possible actual military working conditions. Four different drug treatments were administered to fatigued subjects. It was found that the drugs were generally superior to placebos in their effects in alleviating subjective symptoms of fatigue and enhancing performance of psychomotor tests. The effects were more pronounced

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<sup>187</sup> W. Platnikoff, et al. *Drug Enhancement of Performance*, SRI Project No. SC-3024, Stanford Research Institute, September 1960.

<sup>188</sup> R. Seashore and A. Ivy. "Effects of Analeptic Drugs in Relieving Fatigue," *Psychological Monographs*, 1953, 67(15), 1-16.

on subjective symptoms. In a military exercise lasting 56 hours (which included fatiguing day and night marches) DL-amphetamine had little effect on either rifle marksmanship or obstacle course time. In another experiment, subjects were officers attending a war staff course. These individuals were involved in a 72-hour program staff exercise in which they were not allowed to sleep during the first 42 hours. It was found that DL-amphetamine did not prevent sleep, improve performance, or impair judgment.

Somerville<sup>189</sup> conducted a study with troops who were kept active from 17 to 56 hours. Their activities included marching, obstacle course running, trenching, and an attack exercise. The performance of the group receiving amphetamines was not superior to that of a control group receiving placebos. As part of the above study, Somerville (like Seashore and Ivy) investigated the effects of amphetamines on judgment of military officers performing staff duty exercises over a period of 72 hours. The officers were given no break initially for 42 hours, but then received a six-hour and four-hour break during the remainder of the exercise. Also, officers who were given 40 milligrams (mgs) of benzedrine did not show significant differences in judgment from those in a control group receiving placebos. Deterioration of performance was not lessened by the drug and little evidence was seen of the drug producing any adverse effects upon judgment.

Cuthbertson and Knox<sup>190</sup> found that 15 mgs of methedrine did not produce any significant differences in the mood and subjective feelings of

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<sup>189</sup>W. Somerville. "The Effect of Benzedrine on Mental or Physical Fatigue in Soldiers," *Canadian Medical Association Journal*, 1946, 55, 470-476.

<sup>190</sup>D. Cuthbertson and J. Knox. "The Effects of Analeptics on the Fatigued Subject," *Journal of Physiology*, 1947, 106, 42-58.

subjects during an 18-mile march after 24 hours without sleep than a similar group which was given placebos.

Davis<sup>191</sup> reported British studies with stimulants carried out during WWII. These studies found that the subject who had taken amphetamines usually judged the effects more favorably than the experimenter.

### Effects on Athletic Performance and Reaction Time

Smith and Beecher<sup>192</sup> made a thorough study of the effects of drugs on athletic performance. Their studies show that amphetamines can produce significant enhancement of athletic performance, even in track and field events (like shotputting) in which endurance or fatigue should not play a major role.

Hollingworth<sup>193</sup> reported the effects of caffeine on reaction time. Small amounts of caffeine produced a decrease in reaction time within two hours. According to Hollingworth, the initial effect of caffeine was a "briskness" leading to false reactions, and a retardation in reaction time followed, possibly because the subject was becoming weary. Seashore and Ivy<sup>194</sup> found a significant decrease in discrimination reaction time after fatigued subjects received 10 mgs of DL-amphetamine sulfate or 5.0 mgs of methamphetamine hydrochloride. Tyler<sup>195</sup> reported that after 60 hours

<sup>191</sup>D. Davis. "Psychomotor Effects of Analeptics and Their Relation to Fatigue Phenomena in Air Crews," *British Medical Bulletin*, 1947, 5 43-45.

<sup>192</sup>G. Smith and H. Beecher. "Amphetamine Sulfate and Athletic Performance, I. Objective Effects," *Journal of American Medical Association*, 1959, 170, 542.

<sup>193</sup>I. Hollingworth. "The Influence of Caffeine on Mental and Motor Efficiency," *Archives of Psychology* 1912, 3(22), 1-66.

<sup>194</sup>R. Seashore and A. Ivy, *op. cit.*, 1953.

<sup>195</sup>D. Tyler. "The Effect of Amphetamine Sulfate and Some Barbituates on the Fatigue Produced by Prolonged Wakefulness," *American Journal of Physiology*, 1947, 150, 253-262.

of sleep loss, the loss in reaction time was counteracted by amphetamines. In the same study, caffeine impaired the ability to maintain arm steadiness, while amphetamines improved performance.

#### Effects on Coordination

The effects of drugs on tracking tasks have been extensively studied. These tasks require the subject to follow a moving target or compensate for movement. Payne, Hauty, and Moore<sup>196</sup> found that a control group (placebo) performed significantly poorer during a four-hour tracking performance than did a group given dexedrine. The performance of the drug group was dose-related, with improvements associated with doses ranging from 1.24 to 12.5 mgs. The higher dose showed greater improvements.

Hauty, Payne, and Bauer<sup>197</sup> studied a four-hour tracking performance in a low-oxygen atmosphere. These workers found that five mgs of d-amphetamine allowed their subjects to maintain their proficiency over the duration of the experiment. In addition, the drug provided complete compensation for the predicted degrading effects of hypoxia. The proficiency of the control group which was given a placebo dropped.

#### Effects on Monitoring Performance

As automated detection and surveillance systems are developed, the operator's role is reduced to that of evaluating and responding to the output of the devices. These types of tasks are extremely boring and

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<sup>196</sup> R. Payne, G. Hauty, and E. Moore. "Restoration of Tracking Proficiency as a Function of Amount and Delay of Analeptic Medication," *Journal of Comparative Physiology and Psychology*, 1957, 50.

<sup>197</sup> G. Hauty, R. Payne, and R. Bauer. "Effects of Normal Air and Dextro-amphetamines Upon Work Decrements Induced by Oxygen Impoverishment and Fatigue," *Journal of Pharmacology and Experimental Therapy*, 1957, 19 385-389.

experimentation was undertaken to see if drugs would make individuals performing under these conditions more vigilant or more alert. As reported by Platnikoff, et al., Payne and Moore<sup>198</sup> tested three groups of subjects for 30 continuous hours. All three groups performed at the same fairly steady rate on the first day. No decline in proficiency was observed for the first 15 hours. After 15 continuous hours, performance fell steeply, improved later, but fluctuated. The group given placebos on the second morning never attained the proficiency level of the first day. The group given the D-amphetamine on the second day demonstrated improved performance which approximated the highest initial level of the first day. This improvement was noted about one hour after administration of the drug. No evidence of letdown in the groups receiving amphetamines was detectable.

Kornetsky, et al.,<sup>199</sup> suggested that tasks which are monotonous and require continuous attention suffer more as a consequence of lack of sleep than performances which do not require continuous attention.

#### Effects on Mood and Subjective Feeling

Nathanson<sup>200</sup> found that subjects, who had been administered amphetamines, reported an increase in energy and a desire and capacity for work.

<sup>198</sup>R. Payne and E. Moore. "The Effects of Some Analeptic and Depressant Drugs Upon Tracking Behavior," *Journal of Pharmacology and Experimental Therapy*, 1955, 115, 480-484.

<sup>199</sup>C. Kornetsky, A. Mirsky, E. Kessler, and J. Dorff. "The Effects of Dextro-amphetamine on Behavioral Deficits Produced by Sleep Loss in Humans," *Journal of Pharmacology and Experimental Therapy*, 1959, 127, 46-50.

<sup>200</sup>M. Nathanson. "Central Action of Beta-Aminopropylbenzene (Benzedrine) Clinical Observation," *Journal of American Medical Association*, 1937, 180, 528-531.

Barmack<sup>201</sup> found that amphetamines did not eliminate boredom and fatigue, but did diminish their effects considerably. In a study by Bahnsen, Jacobsen, and Thesleff,<sup>202</sup> using amphetamines, it was found that, besides the lessening of the effects of fatigue, there was a considerable increase in wanting to work along with the feelings that amphetamines made the task easier to perform.

Tyler<sup>203</sup> conducted a series of studies on performance of large groups of men who were forced to remain awake for as much as 112 hours. In one experiment lasting 72 hours, it was found that amphetamines administered every 8-12 hours, starting either at the thirty-sixth or forty-eighth hour of being awake, made it easier to stay awake. Davis<sup>204</sup> found that amphetamines increased feelings of alertness in subjects kept awake all night. The subjects reported mild elation and did not suffer from the tensions usually experienced by subjects during the study. They reported fewer feelings of doubt, anxiety, and discomfort. Alwall<sup>205</sup> found that soldiers experiencing three nights of exertion with little sleep in the daytime reported that their outlook had improved after taking benzedrine

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<sup>201</sup>J. Barmack. "The Effect of Benzedrine Sulfate (Benzyl Methyl Carbinamine) Upon the Report of Boredom and Other Factors," *Journal of Psychology*, 1938, 5, 125-133.

<sup>202</sup>P. Bahnsen, E. Jacobsen, and H. Thesleff. "The Subjective Effect of Beta-phenylisopropylaminsulfate on Normal Adults," *Acta Med. Scan.*, 1938, 97, 89-131.

<sup>203</sup>D. Tyler, *op. cit.*, 1947.

<sup>204</sup>D. Davis, *op. cit.*, 1947.

<sup>205</sup>N. Alwall. "Frequency and Duration of the Subjective and Secondary Effects of Benzedrine and Parvutin on Intensely Fatigued Persons," *Acta Med. Scan.*, 1943, 114, 6-32 (Psychological Abstracts, 20:90).

or pervitin on the morning of the third day. They also reported that they felt less fatigued.

#### Length of Time That Drugs Are Effective

Hauty and Payne<sup>206</sup> indicated that 5.0 mgs of dexedrine was effective in eliminating the effects of fatigue for over a seven-hour period. Cuthbertson and Knox<sup>207</sup> indicated that the first administration of benzedrine was effective in alerting subjects for 12 to 16 hours, while a second dose was effective for only five to eight hours. Payne, Hauty, and Moore<sup>208</sup> suggested, however, that a given dose of dexedrine has a "constancy of effect that is independent of work decrement level." In other words, a given dose of dexedrine should always improve performance by a specified amount, no matter how tired the subject.

Most of the investigations on drug effects reported in this section suffer from the difficulty that the time sequence for the particular drug effect is usually unknown, i.e., when the drug effect is maximal and what the slope of the curve relating time since administration and drug effect might be. It is also unknown whether there are individual differences in these respects, and whether differences in dosage produce differences in the slopes of these curves.

#### General Conclusions

Platnikoff, et al.,<sup>209</sup> summarized the literature on the effects of drugs on performance, and concluded that the evidence indicated that

<sup>206</sup>G. Hauty and R. Payne. "Methods for Mitigation of Work Decrement," *Journal of Experimental Psychology*, 1955, 49, 60-67.

<sup>207</sup>D. Cuthbertson and J. Knox, *op. cit.*, 1947.

<sup>208</sup>K. Payne, G. Hauty, and E. Moore, *op. cit.*, 1957.

<sup>209</sup>N. Platnikoff, et al., *op. cit.*, September 1960.

performance can be enhanced by drugs. But they also indicated that a wide range of behavior (from shotputting to monitoring a clock face) is affected in this way. Barmack<sup>210</sup> found that the greatest difference between amphetamines and placebos was on adding numerals, which occurred toward the end of the work period. The control subjects reported feelings of boredom, irritation and inattention. Kornetsky, et al.,<sup>211</sup> found that D-amphetamines improved performance only in subjects suffering from sleep loss. Newman<sup>212</sup> also found that prolonged sleep loss was necessary before an improvement could be shown on complex psychomotor performance. Mackworth's<sup>213</sup> results showed no enhancement, only a restoration by amphetamines to normal performance on a vigilance task. However, drugs were able to forestall the decline in proficiency with time.

There are strong indications that amphetamines can produce effects in excess of a mere restoration of normal levels of performance degraded by various factors. The cost involved to obtain the enhancement may be excessive, both from the standpoint of physiological and psychological factors. However, except for reports of insomnia, the subjective effects of normal dose amphetamines is generally favorable.<sup>214</sup>

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<sup>210</sup>J. Barmack, *op. cit.*, 1938.

<sup>211</sup>C. Kornetsky, *op. cit.*, 1959.

<sup>212</sup>H. Newman. "Effect of Amphetamine Sulfate on Performance of Normal and Fatigued Subjects," *Journal of Pharmacology and Experimental Therapy*, 1947, 89, 106-110.

<sup>213</sup>N. Mackworth. *Researches on the Measurements of Human Performance*, HM Stationery Office, London, England, 1950.

<sup>214</sup>N. Platnikoff, et al., *op. cit.*, September 1960.

### Summary and Implications

If using drugs to enhance performance is to be considered by military planners, then the conditions under which drugs would be used must be defined. Literature defining the enemy Threat indicates that nuclear warfare is likely. In addition, they have the capability to use chemical and biological warfare. The future battlefield is envisioned as an initially high-intensity conflict, one stressing large armor formations moving rapidly in a fluid ground-gaining environment. Continuous 24-hour combat lasting for days seems to be indicated. Crews may get little or no rest. Relief of crews or units may not be possible. If warfare is to be conducted under the above conditions, the use of drugs to enhance performance may become the only alternative. At the present time no other approach shows as much promise in alleviating the effects of fatigue and sleep loss.

How long drugs can alleviate the effects of fatigue and sleep loss is not definitive. Their effectiveness also seems to lessen with continued use. The use of drugs during the initial stages of future conflicts may seem reasonable, but sooner or later the effects of such combat will take its toll. At the present time we can expect that tank crews can operate with little degradation for periods up to 48 hours. How much longer they can be expected to perform, with or without drugs, is not well defined. We still need to know the costs involved in drug usage before we can ascertain the practicality of using them.

### Toxic Environment (Chemical/Biological)

Chemical warfare, in the form of widespread use of a variety of gases, was instituted during WWI. However, since that time, chemical warfare has not been used in a major engagement. Biological and radiological weapons are more recent additions to the arsenals of the world. Over the intervening years, a large amount of research has been devoted to the physical effects engendered by these agents. This experimentation has been generally restricted to laboratory-type studies, with only a small percentage involving operational situations in the field. The training undertaken by the Army applies especially to the psychological hazards of the threat of exposure to these agents. In particular, this training stresses that this hazard can best be overcome by an understanding of the principles involved and by the development of procedures to be followed in the event of exposure.

Combat personnel are provided with individual protection against chemical agents when operating under threat of an enemy chemical attack. Different types of chemical protective clothing are available for wear in different weather conditions, as well as for special-purpose environments. Both permeable (clothing that allows the passage of air and moisture through the fabric) and impermeable protective suits are currently in the inventory. If an enemy chemical attack is anticipated, combat troops normally will be issued Standard-A permeable chemical protective clothing. The overgarment is intended to be worn directly over the duty uniform; however, in high temperatures, it may be worn directly over underwear. The overgarment is not designed to be decontaminated and reimpregnated for reuse. It is discarded within six hours after being contaminated

with liquid chemical agents or when it becomes worn or ripped to the extent that it cannot be repaired.

Tank crewmen are equipped with a protective mask which is coupled to the tank gas-particulate filter unit which forces air to the facepiece, thus enhancing the wearer's comfort in hot weather. When the mask is worn outside the tank, the individual inhales air through the protective mask canister. An anti-fogging kit is a component of the mask. For protection against a biological agent attack, there is also a protective mask with an attached protective hood. This mask and head arrangement gives complete protection against aerosol-type biological agents.

Because of potential enemy chemical attack capabilities, it is probable that a massive amount of chemical agent will be delivered on our units in an extremely short period of time during such an attack. To counter this, US personnel who are under the threat of an enemy chemical attack must wear their protective clothing and masks at all times -- unless their duties, the weather, or personnel needs prevent it. In these instances, they will remove only that amount of protective clothing and equipment for the time required to perform these duties, etc. The amount and degree of protection in a given situation is usually determined by the unit commander. Generally, personnel must adapt to wearing protective clothing and equipment for extended periods because of the effort and time required to put them on.

Due to the various military situations, unit missions, duty requirements, and basic human needs, it is almost impossible to permit personnel to remain totally protected against chemical agents at all times. Further, individuals operating at high work rates while wearing chemical protective

clothing may experience heat exhaustion (dizziness and faintness) at any time, especially during periods of high temperature and humidity. Also, individuals wearing protective gear will tend to experience fatigue resulting from such factors as difficulty in breathing while wearing a mask, increase of body temperature from work energy and solar heat, and psychological and physiological stress. Fatigue will increase the need for sleep and rest in order to maintain individual alertness and efficiency. Finally, individuals cannot be in full protective gear for indefinite periods and still attend to certain personal needs such as eating, receiving medication, caring for wounds, shaving, and elimination of body waste. Therefore, it will be necessary to provide chemical collective protection shelters for personnel to permit them to rest and take care of their personal needs.

In order to counter the possible effects of CBR warfare employed by the enemy, the military has adopted what is called the Mission-Oriented Protective Posture (MOPP). This allows the commander options and compromises to assure the accomplishment of the unit mission with minimum risk of casualties. This posture requires personnel to wear individual chemical protective clothing and equipment consistent with the chemical threat, work rate imposed by their mission, temperature, and humidity without unacceptably degrading their efficiency from the effects of heat stress, psychological stress, etc.

Hodge,<sup>215</sup> in his presentation to the Conference on Continuous Operations in 1971, commented on the need for long-term exposure criteria to atmospheric pollutants such as fumes, vapors, etc.

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<sup>215</sup>D. Hodge, *op. cit.*, April 1972.

MIL-STD 1472A<sup>216</sup> provides typical design guidance. It states:

Personnel shall not be exposed to toxic substances in excess of the threshold limit values contained in the American Conference of Government Industrial Hygienists -- Threshold Limit Values....

A threshold limit value definition was adopted by the American Conference on Government Industrial Hygienists (ACGIH) and reads as follows.<sup>217</sup>

Threshold limit values refer to airborne concentrations of substances and represent conditions under which it is believed that nearly all workers may be repeatedly exposed day after day without adverse effect....

Threshold limit values refer to time-weighted concentrations for a 7 or 8-hour workday and a 40-hour workweek. They should be used as guides in the control of health hazards and should not be used as fine lines between safe and dangerous concentrations....

...They are not intended for use...in estimating the toxic potential of continuous uninterrupted exposures....

To evaluate continuous operations in this area, Hodge recommended the following:

- a. long-term exposure criteria for five days,
- b. estimates of the effects of eight-hour limit exposure levels experienced for periods longer than eight hours,
- c. an Army document which treats the problem of long-term exposure.

Hodge concluded his remarks with the recommendation that an Army agency specializing in toxicity problems, such as the US Army Environmental Health Agency, should be requested to develop the needed recommendations and

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<sup>216</sup>Military Standard 1472A, *op. cit.*, May 1970.

<sup>217</sup>*Threshold Limit Values of Airborne Contaminants and Intended Changes.* American Conference of Governmental Industrial Hygienists (ACGIH), Cincinnati, Ohio, 1970.

define any new research which may be required for long-term exposure to toxic fumes and vapors.

#### Effects Upon Performance Using Breathing Apparatus

Comte<sup>218</sup> studied the effect of three different types of masks on human performance in an industrial setting. Over all mask conditions, it was found that the perspiration accumulation caused considerable discomfort to the wearer. Also, for all mask conditions, excessive rises in the physiological cost of work were found to accrue. The stress indicated by the physiological changes was found to be largely due to design faults in the breathing apparatus of the various masks. In particular, some of the major problems experienced were: (1) existence of large dead spaces in the facial part of the masks; (2) excessive resistance to breathing; and (3) inability of the masks to supply an adequate air supply. Comte recommended that when using a mask, 30-minute work periods, which are associated with loads of 230 to 390 kilograms per minute, should be followed by a 30-35 minute rest period.

Burgess, et al<sup>219</sup> have found that men can subjectively scale differences in actual breathing resistance while using the M17 chemical protective mask. Further, differences in work rate alone were found to produce distinguishable differences in the sensation of breathing resistance.

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<sup>218</sup> T. Comte. *Assessment of Organism Efficiency While Working in Breathing Apparatus*, Library Translation No. 1699, Royal Aircraft Establishment, (translated from Polish by R. Wolski), May 1973.

<sup>219</sup> W. Burgess, H. Wolper, H. Stoudt, and R. Woodcock. *Studies on Performance Factors in Protective Mask Design*, EACR 1310-22, Department of the Army, Headquarters, Edgewood Arsenal, Aberdeen Proving Ground, Maryland, December 1972.

Montague, Baldwin, and McClure<sup>220</sup> measured the effects of wearing the CBR protective mask while performing selected types of military activities. Measurements were taken after wearing the mask for one hour, and again after the mask was worn for five consecutive hours. Subjects performed under hot daylight conditions with short unmasked breaks every two hours. It was concluded that the average loss in performance attributed to masking was less than 10 percent. The tasks studied were: (1) vigilance while driving; (2) radio communications; (3) unaided target detection (no optics); (4) aided targets detection (optics); (5) weapon firing; (6) cross-country running; and (7) verbal communications. The authors reported that in a subsequent chemical corps experiment in cooler weather, it was found that men could wear the mask for at least 68 hours with no particular difficulty, if given short breaks every two hours.

Researchers in a Combat Developments Command Experimentation Center (CDCEC) study<sup>221</sup> found that military subjects experienced difficulty in seeing, breathing and maintaining their sense of balance while wearing a protective mask. To minimize the visual and breathing difficulties, the subjects soon began to pace themselves slower. The visual and balance difficulties were presumably due to the reduced FOV afforded by the mask. This reduced field made it impossible for an individual to see the ground at his feet without inclining his head. In addition, voice communications

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<sup>220</sup>W. Montague, R. Baldwin, and A. McClure. *The Effects of Wearing the CBR Protective Mask Upon the Performance of Selected Individual Combat Skills*, Technical Report 57, Human Resources Research Organization, Alexandria, Virginia, June 1959.

<sup>221</sup>*Road Battalion Operations in a Toxic Environment: Volume I of III. Operational Capability Experiment*, CDCEC 63-4, HQ, Department of the Army, Combat Developments Command Experimentation Center, Fort Ord, California, December 1963.

while dismounted were difficult to understand. It was recommended that: (a) the M17 mask be modified to allow for drinking; (b) the mask filter pads be improved to increase the sweat absorption capability; and (c) the mask be equipped with a voice emitter for providing voice communications when the wearer is dismounted.

Eichna, et al.,<sup>222</sup> has also investigated the effects of three different methods of protecting tank crews against chemical warfare agents. The three methods were: (1) individual masks and protective clothing; (2) ventilated faceplate connected to a central air system; and (3) collective protection of the entire tank under positive pressure. The ambient temperature conditions under which the study was conducted was hot with DBTs ranging from 88° to 103°F. Also, the daily temperature averages during the study were 96.3°F DBT and 77.8°F WBT. Of the three methods, the mask was considered the least comfortable, primarily due to the breathing resistance. Further, while wearing the full impregnated chemical clothing, the loader and tank commander were incapable of performing their normal duties, which caused the tank to be rendered inoperable. The sole objection to the positive-pressure system was heat accumulation in the turret, due to the poor distribution of air. It was concluded that under the climatic conditions of the study, the combat mask with impregnated clothing offered a simple method of protection, which with further improvement, could result in nearly optimum protection.

#### Effects Upon Performance During Tactical Operations

GDCEC<sup>223</sup> undertook a major field study to investigate the effects of wearing chemical protection gear on the performance of a reinforced ROAD

<sup>222</sup>L. Eichna, R. Walpole, W. Shelley, and J. Whittenberg, *op. cit.*, 1944.

<sup>223</sup>Road Battalion Operations in a Toxic Environment, *op. cit.*, 1963.

infantry battalion in a series of 74-hour problems. The primary finding in all phases of the experiment was that the wearing of chemical protective gear was associated with progressive individual and unit ineffectiveness over prolonged periods. However, it was also found that wearing this protective gear did not cause significant initial mechanical degradation of performance. The symptoms exhibited by individuals indicative of performance degradation were: slowing of pace, loss of motivation, dulling of mental alertness, increased irritability, thirst, hunger, and face irritation caused by the protective mask. Depending on the outside temperatures and the level of energy expenditure, unit effectiveness was degraded in that increasing numbers of heat casualties (which were likely to have been induced by the protective suit) occurred as a function of time. However, before fatigue, discomfort, and the effects of dehydration and body heat buildup appeared, well-trained personnel could perform all tasks about as well wearing a protective suit as they could without the suit.

Performance under two suit conditions (open and closed) was also compared. The "open suit" consisted basically of two layers of impregnated clothing and the M17 protective mask. The "closed suit" was the same except that the outer garment collar was kept buttoned, a protective hood was worn over the head, and a mask and long cotton gloves were worn over the field jacket cuffs.

The CDCEC researchers also looked at tank crew performance under realistic field conditions. During these exercises, crews kept the tank blower system in operation. However, the temperature inside the tank was still slightly higher than the outside temperature (80°-85°F WBGT). Even

under these conditions, the tank crews were able to complete each two-hour exercise without difficulty. The tank crewmen, with the exception of the driver, expended little energy under the conditions of the test. They found that inside suit temperatures were independent of ambient temperatures in WBGT ranges above 75°F. Tank commanders reported that it was almost impossible to clear stoppages and load the caliber .50 machinegun, due to interference from the protective gloves, mask and hood. Tank gunners experienced difficulty in using the primary and secondary firing sights. To obtain a correct sight picture, the eye had to be placed closer to the sight than the mask would allow. In doing this the gunner applied too much pressure against the mask, which caused a depression in the semi-flexible facepiece. After firing, the gunner would push the mask back into its original shape with his hands. Loaders reported problems in removing rounds from the floor ready racks and loading them in the main gun. They also had trouble in checking the recoil replenisher tape and loading and clearing the coaxial machinegun. All of the loader's problems were related to the wearing of the protective gloves and did not appear to be major. It was felt that these difficulties could be overcome through specific training of the loader. The canister and hose of the collective protection system caused some restriction of body movement, especially for the tank commander.

Under tactical operating conditions, Eichna, et al.,<sup>224</sup> found that when tank drivers reached or came close to their limits of tolerance (when wearing protective gear), their driving became more rough. In particular, there was a tendency for drivers to take bumps on the fly and

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<sup>224</sup>L. Eichna, R. Walpole, W. Shelley, and J. Whittenberg, *op. cit.*, 1944.

to hit trees. Under normal conditions, driving was excellent, careful, and well done. In firing the main gun when the tank was buttoned-up, no differences were noted in target acquisition and firing, whether or not combat masks, ventilated facepieces, or no protection equipment were worn.

#### Individual and Unit Stay Times

In the CDCEC study,<sup>225</sup> it was found that in high WBGT ranges (75-90°F) that infantry units were able to operate effectively (at high energy expenditure rates) for approximately 20 minutes for a two-man radar team while wearing a closed CBR suit, and about 90 minutes in the case of a rifle platoon conducting an attack. Time of effective functioning while occupying a defensive position exceeded 20 hours. In this study they found no differences resulting from the wearing of protective gear in terms of either overall levels of performance or learning rates. This applied to tactical performance, information processing, accuracy of discrimination reactions, learning in a complex problem-solving task, and accuracy in communication of abstract messages. However, when measures of quantity or rate of output were used, along with measures of accuracy, there were differences associated with wearing protective gear. It took more time for individuals in the open or closed suit conditions to achieve accuracy than for those in the free suit condition. In moderate WBGT ranges (30°-75°F), performance during an attack in the open suit became degraded after seven hours. Performance of personnel in the closed suit declined after only two hours. Subjective observations concerning troop behavior reported that leaders lost control of their units, troops became

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<sup>225</sup>*Road Battalion Operations in a Toxic Environment, op. cit., 1963.*

irritable and lost interest in the tasks at hand, formations were ragged, and there was a reduction in the number of personnel firing their weapons. At low energy rates, units were able to remain effective for as long as 31 hours.

Casualties in the defensive conditions (low energy rate) were due, with few exceptions, to water deprivation, body water loss, and general fatigue rather than to an excessive buildup of body heat. Similar findings were reported for the offensive exercises.

These researchers concluded that the amount of stay time for a unit is dependent on the ambient temperature and the rate of energy expenditure. Under a high rate of energy expenditure and an outside WBGT range of 75°-90°F, the tolerable stay time varied from 30 minutes to not more than two hours. Under these conditions, individuals in open suits lasted slightly longer than those in closed suits. Further, it was concluded that *acclimatization to heat by personnel does not appear to improve the individual's ability to withstand heat stress when enclosed in either the open or closed suit.* Stay time during moderate WBGT (30°-75°F) varied from six to ten hours. At low energy rates in a high WBGT while preparing a defensive position, units remained effective from 20-25 hours.

In a low energy situation at moderate WBGT (30°-75°F), tolerance times were about the same for both open and closed suits and averaged 20-30 hours. The major factors contributing to casualties under this condition were seen to be deprivation of water, which resulted in physical exhaustion from excessive body water loss and resulting physiological damage.

### Compatibility of Protective Wear With Task Performance

The CDCEC study<sup>226</sup> found that most of the difficulties with the protective mask diminished as personnel became adapted to wearing the mask. The difficulties experienced while wearing the mask in the use of optical instruments, such as the tank gunsight, and the inability to use the mil scale in the binoculars, could be eliminated only by the modification of the mask or modification of the optical instruments. The protective gloves hindered those tasks which required a fine tactile sense or the manipulation of small objects.

Dickinson, Eckles, and Mullen<sup>227</sup> conducted an evaluation to determine if the fire-control components and the protective equipment worn by the tank crewmen were compatible when used by the operator as a total system. The M25A1 protective mask and the T56 protective helmet were used in the evaluation. Vehicles used were the M60A1 and M60A1E2 tanks and the M551 armor airborne reconnaissance vehicle. The authors found that, in general, the protective mask was incompatible with the brow pads. It was found that the peripheral portions of some brow pads deformed the mask lens. Of the three brow pads examined, there was an interfacing problem between all three brow pads and the man wearing a protective mask. The mask was deformed by the eyepieces of the telescope, periscope, and rangefinder. In the M60A1E2, approximately 65 percent of the field of view was lost with the XM50 periscope when the mask was worn. They also

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<sup>226</sup>*Ibid.*

<sup>227</sup>N. Dickinson, A. Eckles, and W. Mullen. *Human Factors Assessment of Equipment Interface Problems Associated With Tank Crewman Protective Equipment*, Technical Memorandum 20-71, US Army Human Engineering Laboratories, Aberdeen Proving Ground, Maryland, October 1971.

found that viewing through the driver's periscope did not appear to cause any problems in judging distance, width, or terrain profile. If length of time is a significant factor, simultaneous donning of the protective clothing by the crew within the fighting compartment was not seen to be effective or practical.

In Phase II of the HEL study conducted by Dickinson, et al., it was found that there was little effect upon the performance of gunnery tasks when wearing the mask and other items of protective equipment. The narrower field of view when wearing the mask did not measurably affect times to fire on clearly visible targets. The authors stated that there is no information as to how the narrower field of view might affect target detection, especially at close ranges.

#### Donning Protective Clothing and Equipment

Dickinson, et al., <sup>228</sup> found that in the M60A1 tank the driver initially took 25 minutes to dress. This was reduced to 16 minutes with four practice trials, excluding the protective hood. An additional four or five minutes was required for the hood, provided the hood was stowed with the protective mask and the buddy-system was used to assist in positioning the hood around the mask and fastening the shoulder straps. Total time could exceed 20 minutes under less than optimum conditions. Only two crew members can dress at the same time -- one in the loader's station and the other in the commander's station. It is not feasible to put the protective hood over the CVC (tanker's) helmet. The hood is too small and renders it difficult for the crewman to operate the communications controls on the helmet. In the M551 and M60A1E2 vehicles, to dress,

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<sup>228</sup> *Ibid.*

the driver must position himself in the loader's station, remove certain rounds of ammunition, and reposition the turret. *Under closed-hatch conditions, ammunition and probably one ammunition rack would have to be removed.*

The protective mask carrier bag, when worn by the gunner on his left side, rubs the carrier as the gun depresses and elevates. If worn on the right side, the carrier interferes with operation of the computer ammunition selection handle. The most appropriate position to wear the carrier for the gunner appears to be over the chest. Some difficulty was reported in operating palm and finger switches and pushbutton controls with the cotton gloves. The cotton gloves caused no problems in operating bore-sighting knobs and levers, toggle switches, and rotating switches. The problems associated with the cotton gloves can be generalized to all gloves.

#### General Comments

As a result of the CDCEC study, it was felt that there is inadequate established doctrine with respect to tactical operations in a toxic environment. Formulation of such doctrine is required. Further, it should consider inclusion of the following techniques: (a) reduced rates of movement; (b) use of vehicles to conduct troop movements (including air transport, even for short distances, whenever practicable); (c) selection of coolest periods of the day or night for conducting tactical operations; (d) frequent rest and rehabilitation in protective shelters when available; and (e) replacement by elements rather than by individuals.

It was also discovered in the CDCEC study that age was a key factor in endurance, and despite otherwise excellent physical condition, personnel

30 years or over fell out earlier on the average than their younger counterparts. It was found that if a body temperature of 105°F was maintained for an appreciable time, interference of the body's heat regulatory system resulted, with a risk of heat stroke, which is often fatal. During the study a limit of 103°F (rectal temperature) was established by the Army Research Institute of Environmental Medicine. This lower limit was adopted because even after a casualty has been stripped and measures taken to cool him have been applied, the rectal temperature may continue to rise as much as two degrees before it starts to drop.

#### Summary and Implications

Stay time within a buttoned-up tank while wearing CBR protective gear is dependent upon many factors. Three of the most significant factors are the outside temperature, type of activity being performed, and the amount of water deprivation.

Although many of the studies reviewed concluded that performance is not affected by the wearing of CBR protective gear, it is interesting to note many of the isolated accompanying statements that occur in these same studies which indicate that there are serious problems due to incompatibility of protective gear and tank equipment and to design limitations of the protective gear itself. Some examples to illustrate the above statement are:

1. The wearing of chemical protective clothing and equipment causes progressive individual and unit ineffectiveness over a prolonged period, but does not cause significant initial mechanical degradation of performance.

2. Progressive ineffectiveness is manifested by slowing of pace, loss of motivation, dulling of mental alertness, increased irritability and discomfort attributable to thirst, hunger, and face irritation caused by the protective mask.

3. The difficulties and inabilities experienced in using certain optical instruments can be eliminated only by the modification of the mask or the instruments.

The above are a few comments which constantly occur when one reads through the studies on effects of CBR gear on performance.

There is a definite need to study the effects of wearing the CBR gear for extended periods of time under high ambient temperature conditions, especially during buttoned-up operations.

Individuals, when operating continuously in a contaminated chemical environment, will need to make some adjustments in their normal routines. They must be able to sleep in protective clothing with the mask. They must shave daily, if possible, to ensure a good seal of the protective mask. The protective mask for armor crewmen does not have a drinking tube capability. In order to drink, the crewman must lift his mask and hold his breath, drink, reseal the mask, and then swallow the water. The pace of action, especially during high ambient temperatures, is much slower than normal. If the work rate of an individual is moderate and the ambient temperature is within 70°-80°F, working with an open suit, the suggested maximum safe unit work time is 30-45 minutes. During ambient temperatures of 85°-100°F under the same conditions, the safe time would be 20-30 minutes. Commanders will have to learn to accept the slower paces and be able to adjust their tactical operations on a realistic basis.

The cumulative effects of wearing protective gear indicate a progressive lessening of performance. The chemical manual (FM 21-40) has tables which provide general guidelines for Army commanders to follow governing work rates for individuals across three broad temperature ranges.

The suggested maximum safe unit work time, even under work rates at cool (50°-70°F) temperatures, is only 60 minutes. A low work rate is characterized by activities which include motorized movement or administrative work.

There appears to be a need for a systematic approach to study the effects on crew and unit performance while wearing protective gear and to accurately measure the amount of degradation if any. The studies which were uncovered by the literature review point to the importance of adequate training programs so individuals can become acclimated to wearing protective gear while performing all their activities, both day and night.

### Sustained and Continuous Operations

It has only been in recent years that the concept of continuous and sustained operations for armor has been discussed seriously. There has always been interest in long-term performance, but there is little in the literature describing present military thinking about continuous operations doctrine. Recent scientific breakthroughs in night vision devices now permit ground forces to operate with near daylight efficiency. Present armored vehicles were not designed or tested to see whether they could be fought for extended periods. It was thought conceivable to operate for extended periods but vehicles were not designed for this specific purpose. As vehicles become capable of operating over wide areas, one of the factors which acts to limit continuous operations is man's limited endurance. To achieve the capability to operate continuously, it is necessary to expand our knowledge of man's performance capabilities and limitations under sustained and continuous operations.

COL Joseph Marks was among the first to attempt to delineate human factors support requirements for continuous operations in a paper under that title delivered at the Army Human Factors Research and Development Conference in November 1969.<sup>229</sup> He stated:

The concept of continuous operations as now being developed does not envision a battlefield environment at which the same level of intensity will last indefinitely.... Significantly, however, the varying operational cycles will be influenced by the unit's capability to fight effectively for longer periods of time and not by the fluctuating environmental conditions of night and day.

... 'Sustained operations' and 'continuous operations' as defined in the concept are separate types of operations. 'Sustained operations' are those smaller unit actions conducted by brigade, battalion, and company for a given number of days to achieve a limited objective. During hours of darkness, there occurs a definite slackening of intensity and applied combat power. In contrast, 'continuous operations' are planned and conducted by division or higher unit, and application of combat power will remain at about the same level of intensity and efficiency throughout the 24-hour period and for periods of fighting extending into weeks.

There is much information which is indirectly related to this area of research, but it is unknown whether these types of operations are feasible.

Barber,<sup>230</sup> Behavioral Sciences Division, OCRD, Department of the Army, made the following comment in reply to a question at the Conference on Military Requirements for Research on Continuous Operations.

At this point, I want to further press upon you the argument that requirements for research related to continuous operations have their origins in and are guided by the activities to be performed....

<sup>229</sup> J. Marks. "Human Factors Support Requirements for Continuous Operations," *Proceedings of the 15th Annual US Army Human Factors Research and Development Conference*, November 1969, pp 130-135.

<sup>230</sup> J. Barber. "Remarks on Research Requirements for Continuous Operations," in D. Hodge (ed.), *Military Requirements for Research on Continuous Operations, Proceedings of a Conference Held at Texas Tech University, Lubbock, Texas, 28-29 September 1971*, Technical Memorandum 12-72, US Army Human Engineering Laboratory, Aberdeen Proving Ground, Maryland, April 1972, pp 1-7.

The question of human performance in continuous operations encompasses so many areas of research that its extent is difficult to define.

#### Military Studies in Continuous Performance

Banks, et al.,<sup>231</sup> evaluated the effects of continuous (48 hours) military operations on soldiers' search performance with a night vision device (Starlight Scope), as well as the effects of continuous performance on live rifle fire and grenade throwing accuracy over a period of 44 hours. During the target acquisition phase, the subjects worked in two-man teams and each individual worked a 30 minute on and a 30 minute off work/rest cycle. No degradation in performance occurred in any of the tasks. A variety of cognitive and perceptual tests were used in the study to predict search performance. However, they did not correlate with performance on the Starlight Scope. The results indicated that the soldiers' efficiency in search performance was related chiefly to their search methods, procedures, and search techniques employed to see and/or recognize targets.

Drucker, Cannon, and Ware<sup>232</sup> studied the effects in the laboratory of sleep deprivation on the performance of armor crewmen over a 48-hour period. Subjects worked in two-man teams: one performing a driving task and the other a target detection task. The effects of job rotation and shift (day/night) were also studied. They found that subjects who

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<sup>231</sup>J. Banks, J. Sternberg, J. Farrell, C. Debow, and W. Dalhamer. *Effects of Continuous Military Operations on Selected Military Tasks*, Technical Research Report No. 1166, US Army Behavior and Systems Research Laboratory, Arlington, Virginia, December 1970.

<sup>232</sup>E. Drucker, L. Cannon, and J. Ware. *The Effects of Sleep Deprivation on Performance Over a 48-Hour Period*, HUMRRO Technical Report 69-8, Human Resources Research Organization, Alexandria, Virginia, May 1969.

worked for 48 hours with sleep performed significantly worse on the driving task than control subjects who were allowed to sleep five hours each night. The difference in performance between the two groups on the target detection task approached statistical significance. Major degradation in performance for the experimental group occurred during the period when they would normally be sleeping. Degradation was much larger the second night compared to the first night. The starting time had no significant effect. The time of day during which work was performed was, however, found to be critical. Degradation was not eliminated by job rotation.

Dobbins, Tiedemann, and Skordahl<sup>233</sup> studied the performance of drivers who were required to drive heavy commercial trucks for nine-hour shifts about two hours of breaks. Subjects continuously monitored a visual discrimination task while they were driving. No decrement occurred in the monitoring task, but there were large differences in driving performance.

Jones<sup>234</sup> investigated radio operator performance during three long-range flights of 15 hours each. The optimum duration of a watch was found to be three hours, after which a constant reduction in performance was noted.

Lindsley<sup>235</sup> studied the performance of radar operators to determine the effects of length and repetition of operating periods on their per-

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<sup>233</sup>D. Dobbins, J. Tiedemann, and D. Skordahl. "Vigilance Under Highway Driving Conditions," *Perceptual and Motor Skills*, February 1963, 16(1), 38.

<sup>234</sup>G. Jones. "Fatigue Effects in Radio Operators During a Program of High Intensity Long Duration Flying," *Aerospace Medicine*, 1960, 31-478-484.

<sup>235</sup>D. Lindsley. *Radar Operator "Fatigue": The Effect of Length and Repetition of Operating Periods of Efficiency of Performance*, OSRD Report No. 3334, 1944.

formance. The eight highly-trained subjects operated a simulated radar display four hours a day, six days a week for 17 days. It was found that a steady loss in signal detection occurred and accuracy of determining the bearing of targets declined. This loss became greater as each period progressed, and as the periods were repeated.

Ainsworth and Bishop,<sup>236</sup> in a field study with 20 tank crews, investigated crew performance over a period of 48 hours without sleep. Performance on the following tasks was investigated: surveillance (moving and stationary), communications, gunnery, maintenance, and driving. The experimental group performed continuously during four consecutive 12-hour activity periods. The control group performed during four 12-hour activity periods, but were given a 24-hour rest between each 12-hour activity period. Compared to the control group, the experimental group showed little performance degradation, except in two of the driving exercises. Only small performance differences were found between day and night. The authors concluded that: activities like moving surveillance and some driving tasks which require a protracted high level of vigilance or complex perceptual-motor activity are the most sensitive to the adverse effects of sleep; performance at night is not significantly affected by diurnal rhythms; and there does not appear to be any need to change the unit's organization or tactical doctrine to accomplish continuous tank platoon operations for periods up to 48 hours. No portion of the study involved buttoned-up operations.

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<sup>236</sup>L. Ainsworth and H. Bishop. *The Effects of a 48-Hour Period of Sustained Field Activity on Tank Crew Performance*, HUMRRO Technical Report 71-16, Human Resources Research Organization, Alexandria, Virginia, July 1971.

### Comments on Continuous Operations

O'Hanlon<sup>237</sup> discussed some of the biological problems that might arise from sustained and continued operations. He pointed out that there is little directly relevant information on how men react during sustained and continuous operations. In addition, studies on men performing physical work over periods similar to those anticipated for a sustained operation have not been conducted. He pointed out that data available suggest numerous potential problems which seem to indicate a serious reevaluation of the viability of current concepts of sustained and continuous operations. With sleep deprivation, man's behavior seems to suggest a progressive deterioration in cerebral function, signifying an almost linear decline (up to 120 hours of wakefulness) in psychophysiological arousal. This decreased arousal may cause deterioration in performance on certain monotonous tasks (such as monitoring) where high arousal seems prerequisite for efficient performance. Also, following sleep deprivation, the capacity for physical work is reduced. This effect will diminish with time, disappearing after several days. O'Hanlon found no report of an investigation in which men had performed under a constant work load for periods which exceeded 24 hours, and that almost no one had measured the recovery of individuals who have worked for prolonged periods.

O'Hanlon further commented at length on hypohydration as being one of the more serious physiological problems in continuous operations. Men

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<sup>237</sup>J. O'Hanlon. "Some Observations From a Literature Review to Anticipate Biological Problems That Might Arise in Sustained and Continuous Operations," in D. Hodge (ed.), *Military Requirements for Research on Continuous Operations, Proceedings of a Conference Held at Texas Tech University, Lubbock, Texas, 28-29 September 1971*, Technical Memorandum 12-72, US Army Human Engineering Laboratory, Aberdeen Proving Ground, Maryland, April 1972, pp 116-132.

do not immediately replace the lost fluid by drinking when unlimited water is available. The water is replaced gradually over hours or days. This slow return to fluid balance may leave individuals behaviorally or physiologically debilitated during the interim. Recovery from hypohydration therefore requires two to three days. The effects of hypohydration could be minimized by forcing individuals to replace lost water and salt. In view of the seriousness of the problem, this measure seems mandatory.

Strydom, et al.,<sup>238</sup> studied the reactions of two groups of soldiers on a 29 kilometer march. One group was permitted to drink water *ad libitum*, and the other group drank accordingly to a restricted schedule. Striking effects on the men's morale were noted. At the start and up to the third hour of marching, distinct differences became noticeable between the two groups. The morale of the restricted group was poor and they became morose, aggressive, and disobedient toward their superiors and showed signs of fatigue. Their response to discipline decreased further towards the latter part of the march. In marked contrast, morale in the *ad libitum* group remained high throughout.

Ayoub, et al.,<sup>239</sup> reported work by Michaels, Hutton, and Horvath,<sup>240</sup> who found that for continuous work on a bicycle or treadmill or walking

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<sup>238</sup>N. Strydom, et al. "The Influence of Water Restriction on the Performance of Men During a Prolonged March," *South African Medical Journal*, 1966, 40, 539.

<sup>239</sup>M. Ayoub, E. Burkhardt, G. Coleman, and N. Bethea. "Physiological Response to Prolonged Muscular Activity," in D. Hodge (ed.), *Military Requirements for Research on Continuous Operations, Proceedings of a Conference Held at Texas Tech University, Lubbock, Texas, 28-29 September 1971*, Technical Memorandum 12-72, US Army Human Engineering Laboratory, Aberdeen Proving Ground, Maryland, April 1972, pp 133-187.

<sup>240</sup>E. Michaels, Jr., K. Hutton, and S. Horvath. "Cardiorespiratory Responses During Prolonged Exercise," *Journal of Applied Physiology*, 1961, 16, 997.

for eight hours without interruption, 35 percent of maximum aerobic capacity could be achieved without fatigue. Fifty percent appears to be the upper limit of work tolerance for eight hours. Only a select group could work at 50 percent of maximum aerobic capacity. Ayoub further stated that:

Intermittent pauses are the most effective way of maintaining or increasing work performance. Although considerable work has been reported on the effects of pauses, whether these may be micropauses or long pauses, it appears that more work is needed to investigate the effects of these pauses during prolonged activities lasting more than 16, 24, or 48 hours of continuous work.

After reviewing the studies and papers which were presented on the subject of continuous operations, it is obvious that there is a need for the military to carefully define the performance requirements they desire. Further, there is no agreement on the characteristics of continuous operations. There are apparent contradictions in some of the assumptions which were used to define the parameters of some studies. Some studies assume there will be provision to provide rest and recuperation, and others assume that prolonged physical activity will be required. If minimum standards can be defined by the military, then research can be undertaken to determine whether these minimum standards can be met.

#### Summary and Implications

Of the studies surveyed, there appears to be a consensus that armor crewmen can perform with little degradation in performance for periods up to 48 hours and in some cases slightly longer. However, none of the unclassified studies reported in this section investigated buttoned-up performance (see Appendix, classified information). The activities in

the studies reported were varied and, in some cases, catnapping was allowed. Studies have not been conducted as yet on men performing physical work over periods similar to those anticipated for a sustained operation. Fall-off in performance has been reported when individuals are required to work when they would normally be sleeping. Continuous performance in the buttoned-up mode, with and without CBR protective gear, has not been widely studied as yet.

From the information available concerning performance while wearing CBR protective gear, coupled with the information on operating under high ambient temperature conditions and the resulting problems created by dehydration, it seems doubtful that continuous operations can be undertaken in high ambient temperatures.

The literature review uncovered no studies in unit performance while operating in the buttoned-up mode. Therefore, it is not known what impact buttoned-up operations will have on armor units. No training program for buttoned-up armor operations existed until MASSTER developed the first prototype training program for use in their field study. Much of the material was screened from British military publications, which provided some background information. MASSTER has also developed a Unit SOP governing buttoned-up operations based on their review of the literature during the initial training program.

## CHAPTER 3

### SUMMARY AND CONCLUSIONS

The information collected during the course of the current research effort indicates that there are two basic reasons why tank crews might button up in a future military conflict. The first is not new to tankers. Typically, when faced with overhead artillery bursts, small-arms fire from infantry, overhead fire from buildings, or fire from aircraft, tank crews may choose to button up (now as in the past) in order to reduce the likelihood of casualties. This is often a "short-term" necessity. As soon as the immediate danger passes, normal open-hatch operations are resumed. The second reason crews may button up is a threat of actual or potential attack by CBR weapons. If the likelihood of these hazards persists, operations in the buttoned-up mode might well become a "long-term" necessity.

One of the Government's primary objectives in sponsoring this research effort was to assess both the short-term and long-term effects of operating in a buttoned-up mode. Unfortunately, precise definitions of the expressions, "short-term" and "long-term," could not be found in the literature. However, general usage indicated that short-term time-frames were measured in minutes or hours, while long-term time-frames were measured in days.

Concern with or interest in long-term operations of any type is fairly recent. It stems partly from the fact that within the past few years equipment and vehicles in the inventory of US forces have become more reliable and, therefore, more likely to function without maintenance for long time periods. However, the major factor precipitating this interest

and concern has been the development of night vision devices and other technological breakthroughs that permit men to function almost as well in darkness as in daylight. These developments have made the constant intensity 24-hour battleday a distinct possibility. As a result, the Army must be prepared to fight a 24-hour battleday, and possibly maintain this pace for days on end.

Writers concerned with long-term operations have used the terms, "extended," "sustained," and "continuous" to describe particular scenarios. While the distinction between these terms is not always clear, the term, "continuous," as generally employed in the literature, best describes the type of operations referred to as long-term in the previous paragraphs. That is, a "continuous operation" is one which lasts for 48 hours or more and which varies in intensity throughout the entire period.

It was against this background that available documentation was sought concerning the psychological (and associated physiological) factors that might affect performance during buttoned-up operations. During the search, it was discovered that little research directly concerning buttoned-up operations had been conducted in this country. However, there was a considerable body of research on topics deemed to be relevant to such operations. As the literature describing this research was examined and analyzed, two major conclusions became increasingly obvious. Stated simply, these are:

- a. The primary immediate effects of buttoning up are a reduction in the fields of view of the tank commander, the driver, and the loader, and a complete restriction on extravehicular activity.
- b. Continuous operations in the buttoned-up mode are not feasible with our present armored equipment.

The remainder of this chapter will be devoted to: (a) very brief statements summarizing the information reviewed which led to these

conclusions; and (b) a summarization of findings from the literature on factors which are assumed to be relevant to buttoned-up operations, but whose actual effects are as yet unknown.

### Conclusion 1

The primary immediate effects of buttoning up are a reduction in the fields of view of the tank commander, the driver, and the loader, and a complete restriction on extravehicular activity.

This conclusion may seem both trite and somewhat obvious. However, it is judged worthy of inclusion and discussion in this report because of its potential impact on future research. In particular, it serves to emphasize that the factors originally identified in the literature as having the potential to degrade performance in the buttoned-up mode may have no effect on short-term operations. Further research may prove this expectation false. However, on the basis of what could be gleaned from the literature, the immediate effects should be only those resulting from the physical restrictions imposed by buttoning up. Therefore, it seems that future research on short-term operations should be focused directly on the problems associated with these restrictions.

For example, with a reduced or restricted field of view, the occupants of a tank are likely to be less able to anticipate the high-amplitude transient motions of the vehicle which often result from negotiating rough terrain. As a consequence, more physical effort will likely be expended in maintaining equilibrium, resulting in greater crew fatigue. Also, the likelihood of both motion sickness and injury is increased under these conditions.

As might be expected, when in the buttoned-up mode, crewmen have difficulty in acquiring targets. They also tend to become disoriented

when traversing the turret during target acquisition. In order to maintain orientation, tank commanders typically reduce their azimuth traversing rates, thereby increasing the overall time between the initial target detection and subsequent target engagement.

Finally, the restriction on extravehicular activity creates communication problems. Arm, hand, and flag signals cannot be employed. The only other currently available means of inter-tank communication is the radio. However, use of the radio overloads the existing radio frequencies which are available for communications, and increases the likelihood of detection by the enemy. In addition, it makes messages more susceptible to interference by electronic jamming. Therefore, it is appropriate (as indicated above) to focus future research efforts with respect to short-term buttoned-up operations to problems such as the above. Assuming that such research could produce practical and relatively inexpensive solution to this problem, it is likely that degradation of combat effectiveness under buttoned-up conditions would be minimized.

## Conclusion 2

Continuous operations in the buttoned-up mode are not feasible with our present armored equipment.

It is not necessary to consider only psychological factors to conclude that continuous buttoned-up operations would be infeasible, other than under a very limited set of conditions. The conclusion is based entirely on physiological and human factors considerations. These considerations, and pertinent related facts, are summarized below:

a. Temperature. Buttoned-up operations in cool or cold climates could be conducted for much longer periods than in warm or hot climates. It has been shown that temperatures inside tank compartments, even with

hatches open, can exceed 100°F in summer weather. It has also been shown that heat prostration casualties among personnel wearing individual CBR gear in a tropical climate began to occur in less than one hour. Since our current armored vehicles alone do not provide adequate protection in a CBR environment, individual CBR gear must be worn for protection while in the vehicle. These facts make it obvious that *at high ambient temperatures, personnel wearing CBR gear could be expected to function for only very short periods of time in a buttoned-up mode.* At low ambient temperatures, protected personnel could function for much longer. However, for these conditions the upper or tolerance limit is determined by the length of time these personnel would go without water. Further, this problem is complicated by the fact that the current protective face mask worn for CBR protection is not designed to allow the wearer to drink water while the mask is firmly in place.

b. Fatigue. The seats in current US Army armored vehicles have not been designed for comfort or long-term occupancy. Except perhaps for the driver's seat, the crew positions in US Army main battle tanks have no provisions for even short periods of relaxation and rest. These facts, coupled with problems in maintaining equilibrium during movement, indicate that continuous operations in the buttoned-up mode would be extremely fatiguing. This factor alone does not make continuous operations infeasible, as a number of studies have shown that man can perform without degradation for 48 hours or more on a variety of tasks. However, fatigue effects will certainly compound the problem of buttoned-up operations.

c. Visibility. Current US Army tanks have no provision (e.g., washer-wipers) for cleaning the external surfaces of viewing optics from inside the vehicle. Rain, especially in the direction of travel, could

severely limit visibility, making target acquisition difficult and travel hazardous. Heavy snows and icing could effectively blind the crew. Mud splashes or accumulation of dust would also likely degrade viewing. This inability to clean viewing devices under adverse conditions could limit the time of occupancy, and degrade performance, dependent upon how badly the field of view was obscured.

d. Storage. Current US Army armored vehicles have no provision for interior storage of supplies necessary for continuous operations, especially while buttoned up. Research indicates that as much as 20 gallons of water may be required for a tank crew during a 48-hour period in high ambient temperatures. Currently, there is no water supply to the tank interior. Storage tanks are five-gallon cans carried on the outside of the turret bustle. Additionally, there is no interior space for stowage of individual CBR gear, personal gear such as hygienic supplies and clothing, food or wastes. In brief, current US Army tanks were not designed to satisfy the storage needs for continuous operations.

e. Resupply. Even if current US Army tanks could carry the necessary supplies to maintain life and reasonable comfort while buttoned up, it is highly doubtful that there is space for the quantity of ammunition and fuel which would be required for continuous operations. The hatches on our current equipment must be opened to take on ammunition and resupplies, and a crewman must dismount to perform refueling operations. Even under otherwise optimum conditions, limited fuel capacity would probably limit operations to less than 48 hours.

f. Waste disposal. Current US Army tanks have no provisions for either accumulating or disposing of human wastes. Equipment for accumulating wastes, such as employed on space missions, could be provided

to tank crewmen. Some system which will seal waste materials into break-proof containers is necessary; otherwise, the odor might become intolerable. Until a waste disposal and storage system is designed suitable for a tank, disposal of wastes will be at least an aggravating problem.

g. Miscellaneous. A number of minor problems might also hamper continuous operations. For example, neither storage space nor facilities are provided in tanks for the conduct of personal hygienic activities. Sponge bathing and brushing of teeth could be accomplished only with great difficulty and, only if sufficient water were available. Other problems, which might prove to be serious in buttoned-up operations, have never been investigated. For example, it is known that noise levels in tanks are high, averaging around 100 dB. However, it is not known whether the level increases with the hatches closed and, if so, if it reaches dangerous levels. Similarly, the accumulation of toxic substances within the tank compartments has not been a serious problem with the hatches open. However, during an intense firefight with the hatches closed, noxious substances could accumulate, making habitation without protection dangerous even in short-term operations. Until factors such as these have been fully investigated, especially in terms of their effects over time, the feasibility of continuous operations in the buttoned-up mode must be further questioned.

#### Other Related Work

Because of the very limited amount of research conducted on buttoned-up operations, one can only speculate on the potential effects of a number of potentially relevant factors. These are factors which have been shown

to be potent in other situations, and may or may not affect performance in buttoned-up armor operations.

Much research on the effects of confinement and/or isolation has been reported in connection with space and undersea programs. Many subjects, even in laboratory experiments, have been unable to endure the conditions imposed and have defected, in some cases, in less than eight hours. Tank crewmen are definitely confined during closed-hatch operations, and except for radio communications, are also isolated as crews. Whether these factors will create serious problems in tanks, when and if continuous operations become feasible, is not known. Tank crewmen are always confined and isolated to a significant degree even during open-hatch operations. It is possible that self-selection results in only those personnel who are capable of enduring the conditions entering or remaining in the armor field.

Needs for privacy and personal space have also been shown to be potent factors in previous research where both were deliberately limited. These factors were recognized by a Canadian group in the development of internal arrangements and life-support systems for a small arctic vehicle. However, there is no indication that they have ever been considered in the development of US armored vehicles. In fact, the work by the Canadians is the only work located which gives anything but lip service to life-support requirements for ground-based vehicles for military or quasi-military organizations.

In the past, US armor crewmen have seldom been confined to their vehicles for extended periods of time. Defecation and urination were most often accomplished during breaks outside the vehicle. Bathing, shaving, and other personal hygienic activities were also performed after dismounting.

In brief, the requirements for privacy and space are in need of further investigation if continuous operations in the buttoned-up mode are to be considered for the future.

Other areas in need of investigation are the effects of buttoning up on combat stress and the appropriateness of selecting crews on the basis of compatibility for long-term combat operations. Crew duties and functions in continuous operations must also be examined to determine whether rest periods are feasible, and if so, how work/rest cycles might be optimized.

Although not formally stated, it is obvious that a third conclusion has been drawn by the authors. They feel that a research program targeted to the problems discussed will be necessary to ensure optimum performance during either short- or long-term operations. Recommendations toward this end are presented in the following chapter. A brief description of efforts underway toward this goal is provided in the final chapter.

## CHAPTER 4

### RECOMMENDATIONS

Throughout the many documents and other information sources reviewed, there were numerous references to problems encountered, or that might be encountered, in buttoned-up operations. However, no attempts to list the design essentials for armored vehicles necessary for conducting buttoned-up operations were located. Nevertheless, as indicated in the previous chapter, our current equipment is lacking in several respects. If our armored forces are to have the ability to fight in environments which require them to close the hatches, even for short periods of time, it is essential that our equipment be designed to support these operations. This chapter is devoted to recommendations aimed at achieving this end.

The chapter is divided into two sections. The first section provides specific recommendations for vehicle design modifications. These suggestions are based on findings from previous works. The second section suggests research areas for a programmatic effort designed to ensure a US capability to engage in continuous operations in the buttoned-up mode in the future.

#### Recommended Design Characteristics for Buttoned-up Operations

The recommendations listed here are suggested as remedies for problems encountered by others and documented in the literature. It should be noted that not all of them will necessarily increase our capability for continuous operations in a CBR environment. Some (e.g., a face mask designed to permit liquid consumption) are designed to extend our current

capability to operate with present equipment. Others (e.g., the provision of toilet facilities) are designed to extend our capability for continuous operations, but will be of no real aid in an environment where individual CBR gear must be constantly worn. Therefore, the modifications recommended should be considered as interim measures only.

1. Water storage tanks should be installed with a minimum capacity of 20 gallons and with an outlet(s) in the crew compartment. If possible, provision should be made in order to prevent freezing in the winter by ducting exhaust or engine coolant around the tanks. Also, the tanks should be pressurized to permit water to be drawn without allowing contaminated air to enter the tank. Finally, the nozzles should be designed to be sealed against contamination, and should be designed for insertion into masks constructed to permit liquid consumption without breaking the seal.

2. A small electric cookstove should be installed. The stove should be removable and easily stored when not needed. As a minimum, the stove should be designed for heating water for coffee or tea, or warming small quantities of other rations. The stove and associated equipment need not be designed for use during movement.

3. A small wash basin should be provided for crewmen to perform minimal personal hygiene activities. Ideally, the basin should be designed to automatically drain into a sealed disposable container.

4. Internal storage racks for personal items (wash cloth, toothbrush, CBR gear, etc.) should be installed.

5. Containers for the accumulation and storage of waste materials should be provided. These should be capable of being sealed to eliminate

offensive odors. Expended main gun casings with a simple plastic snap-cap might be suitable for some types of waste.

6. Provisions should be made for urination and defecation within the crew compartment. One possible solution is slipon urinals at each crew position and a chemical toilet under one of the seats.

7. All optical devices should be provided with washers, wipers, de-icers, and de-foggers.

8. Seats should be redesigned to: (a) provide a greater range of adjustments, (b) provide better damping to absorb vibration and shock, (c) permit the incorporation of reel-type restraining harnesses, and (d) enable crewmen to rest or relax for brief periods. (The possible incorporation of a foldaway bunk at one position should be considered as an alternative. It could be used alternately by crewmen as duties permitted.)

9. Provision should be made during extreme cold for ducting warm air over hands and critical control surfaces.

10. Each crew position in the main compartment should be provided with: (a) footbraces, (b) handholds and crashpads, and (c) reel-type restraining harnesses to improve stability and safety while moving.

11. Hatch openings should be enlarged and modified to permit crewmen to enter and exit while wearing CBR protective gear.

12. The face mask should be modified to permit crewmen to drink from sealed containers. Similar systems have been used in space, and could serve as models.

The list presented is certainly not exhaustive. However, it does address many of the major problems reported in the literature.

## Recommendations for a Programmatic Research Effort

The research areas outlined below are conceived of as belonging in a long-range research program oriented toward providing the US with more than just a modest capability to conduct operations in environments requiring closed hatches.

Development of Sealed Compartments. Work should be initiated to determine the problems involved in and the costs of sealing the crew compartments from the outside atmosphere. A single filter system with a blower that generates a slight overpressure should provide the crew with considerable protection from CBR agents. At worst, it should give crewmen ample time to take other individual protective measures.

Development of a "Fighting Suit." The suit should be designed to heat, cool, and provide uncontaminated air to the crewman. The suit would serve as backup measure in a vehicle with sealed compartments. Also, if a crewman had to dismount for emergency repairs, the suit would provide protection against the environment. The suits and the vehicles should be designed with an umbilical arrangement so that a crewman could "plug in" to the life-support systems while outside the vehicle. The suit should be designed with a slipon urinal, and some provision should be made for either internal storage or a means of voiding the urinal in a storage container in the compartment.

Development of Adequate Ventilation Systems. The adequacy of current ventilation systems for operation in the buttoned-up mode has not been fully investigated. Even when crews are not operating in a toxic environment, the internal air may become toxic during a sustained fire-fight in a stationary tank on a windless day. The internal concentrations

of various contaminants under such conditions must be determined, and new ventilation systems must be designed if the current systems are not adequate. Also, it may be necessary to incorporate a dehumidification capability to prevent condensation in the compartments.

Determination of Optical System Requirements. Restricted vision during buttoned-up operations is a major problem. Optics which provide a greater field of view, or a field more suitable for buttoned-up operations, might greatly enhance crew performance in target acquisition and reduce disorientation problems. For example, a stabilized surveillance system which combines a wide-angle, low-power unit with a high-power or variable-power (step-zoom) unit may prove necessary. In any event, requirements must be determined.

Determination of Requirements for Automatic Target Designation and/or Acquisition Systems. A target designation system which would permit a tank commander to automatically slew the turret and the gunner's sights to the azimuth and elevation of a second device would greatly reduce original acquisition to engagement time. The tank commander's device could be small and easily aimed by hand. This system would increase the probability of US forces being able to fire the first shot.

An automatic target acquisition system would serve the same purpose as the target designation system. However, the system would have a means (most likely an infrared sensor) of seeking out potential targets, and would automatically slew the turret and the gunner's sight to the proper azimuth and elevation.

Determination of New Crew Selection and Training Requirements. Personnel requirements for buttoned-up operations have only been examined in a cursory fashion. A task and skill analysis of buttoned-up operations

needs to be conducted to determine whether new job requirements exist for which training must be designed. For example, personnel will very likely have to be trained to maintain the life-support systems installed. Other areas in the personnel area that should be examined are: (a) the need to select crewmen on the basis of their ability to endure confinement and isolation, (b) the need to compose crews on the basis of personal compatibility, and (c) the need for personnel with new or different psychophysiological characteristics.

Examination of Additional Human Factors Requirements. A number of recommendations for changes to equipment were made in the previous section of this chapter. However, other materiel should be examined from the human factors standpoint. For example, the compatibility of the face mask with various optical gear needs to be considered. Actual minimum work space requirements for each crew position must also be ascertained. This latter determination should be made with the assumption that the crewmen will be wearing CBR protective gear. Finally, the development of prepackaged individual personal hygiene kits should be considered. The use of such kits would ensure that necessary supplies were on board, and that only the minimum storage would be required.

## CHAPTER 5

### ONGOING RESEARCH

After a review of the available literature and other information sources, three studies of an exploratory nature were planned. These studies are all concerned with the improvement of short-term buttoned-up operations. The results of these efforts will be reported at a later date. In brief, these research efforts are concerned with:

#### Evaluation of the Low-Profile Hatch

The Israeli Defense Forces developed the low-profile hatch as an alternative to buttoning up. In recent conflicts, their personnel losses among tank commanders were considered unacceptable. However, they apparently also felt that buttoning up would result in unacceptable performance degradation. Therefore, they developed a new hatch cover. The cover permits the tank commander to view the terrain through an opening between the hatch and the cover, while still affording considerable protection against overhead artillery, sniper fire, and antiaircraft attack. The Israelis employed the modified hatch cover only at the tank commander's position. However, it might also be of considerable value to the driver, and possibly even the loader.

This research will attempt to determine the amount of degradation (if any) in performance to be expected in using the low-profile hatch on both the driver and tank commander's positions. Drivers will be tested on a driving course, and tank commanders will be tested on target acquisition performance.

In addition, the study will attempt to define the best hatch opening in terms of achieving an optimal balance between vision and protection.

### Alternative Command and Control Methods

The use of arm, hand, and flag signals has been strongly advocated as part of what is termed the *new tactics*. The use of these signals frees radio channels for other purposes, reduces the probability of detection, and foils electronic jamming. However, the use of these signals will not be possible while buttoned up. Therefore, alternate means of communication are needed.

HumRRO has proposed the use of a detachable light panel on the rear of each tank to transmit standard command and control messages. The panel has the additional advantage of being usable during both day and night. When completed, this study will provide data comparing (a) response times to commands, and (b) radio communication loads between standard open-hatch command and control techniques and the light panel technique.

### Determination of Optimum Turret Traversing Rates

Reports from the literature, as well as interview reports, indicate that the tank commander is likely to become disoriented while traversing the turret during buttoned-up operations. The interviews further indicated that commanders often decreased azimuth rates in order to prevent disorientation. It was theorized that the faster rates of traverse caused blurring through the vision blocks. Therefore, this study was conceived to determine optimum slewing rates for buttoned-up operations.

In this study, times to transfer the target from the tank commander to the gunner will be obtained for the open-hatch condition, and for selected slew rates in the buttoned-up mode.

### Preliminary Findings

Of the three exploratory efforts, work was first begun on the determination of optimum turret traversing rates. The tank commander in the M60A1 tank uses what is normally referred to as the *tank commander's override control handle* to lay the turret in azimuth and the main gun in elevation onto the target. In order to control the azimuth rate of the turret, a device was fabricated which fit onto the override handle. The device can be adjusted to allow control of the traverse speed at any maximum within the total capabilities of the hydraulic system.

Using man-made targets (boresighting panels, buildings, etc.), an experienced tank commander ran through a number of target acquisition trials in the buttoned-up mode. The following independent variables were manipulated: (1) maximum turret traverse speed, (2) target offset (in mils) from the zero axis of the main gun, and (3) direction of gun lay onto the target (right to left, left to right). For these trials, the caliber .50 machinegun was pointed to the rear. This was done to eliminate the "blindspot" in the field of view, which could occlude targets if the machinegun were in its normal forward position.

Originally, the tank commander moved the override handle to the maximum speed position to overcome the turret inertia. Once the turret was moving, the control was moved to maintain a slower constant rate until the target azimuth was reached. Time to lay on the target in this mode was slower than in the open-hatch mode for the same conditions.

On later trials, the tank commander was able to lay on target as fast in the buttoned-up mode as in the open-hatch mode. He accomplished this by selecting an external reference on the cupola to lay on the target before making final adjustments with the rangefinder sight. The

external reference in this case was a machine "nut." In other words, instead of using the main gun as a reference, he first traversed to lay the nut on the target.

This preliminary result indicates that the problem in acquiring targets observed previously may not be due to blurring at all. Rather, the problem may have been due to a lack of procedural guidance and lack of experience in operating while buttoned up. If this hypothesis proves to be correct, a training program in procedures rather than a slew rate control mechanism will probably solve the problem.

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